

Assessment of the effects of diets containing DDGS with supplemental tallow on fat digestibility, growth performance, carcass and pork fat quality in growing-finishing pigs

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## Table of Contents

	Page
<b>Acknowledgements</b>	i
<b>Table of Contents</b>	ii
<b>List of Tables</b>	iv
<b>List of Figures</b>	v
<b>Chapter 1. Literature Review</b>	
Introduction	1
Understanding Fiber Utilization in Pigs	5
-What is Fiber?	5
-Fiber Digestion	7
-Hindgut Fermentation	8
Understanding Lipid Utilization in Pigs	9
-Types of Lipids	10
-Fatty Acid Characteristics	11
-Iodine Value	14
-Iodine Value Product	15
-Fat Digestion and Absorption	15
-Fat Deposition	19
- Regulation of Fat Deposition	21
-Fatty Acid Digestibility	22
-Fat Sources and Types	23
-Benefits of Supplemental Fats in Swine Diets	24
-Methods to Evaluate Fat Content	24
-Fat Source Quality	25
DDGS as a Feed Ingredient in Swine Diets	26
-Growth Performance and DDGS	26
-Effects of Feeding DDGS Diets on Carcass Characteristics	27
-DDGS Effects on Pork Fat Quality	28
-Pork Quality and DDGS	30
-Strategies to Improve Pork Fat Quality when Feeding DDGS	30
-CLA and Ractopamine	31
Tallow as a Supplemental Fat Source	32
-Digestibility	32
-Growth Performance	33

-Carcass Characteristics	34
-Fat Quality	34
-Pork Quality and Tallow	35
DDGS and Tallow Interactions	35
-Growth Performance and Carcass Characteristics	35
-Fat and Fiber Digestibility	37
Digestibility Procedures	37
Summary	40
<b>Chapter 2. Effects of adding supplemental tallow to diets containing 30% DDGS on growth performance, carcass characteristics and fat quality in growing-finishing pigs</b>	41
Overview	42
Introduction	44
Materials and Methods	45
-Animals	45
-Dietary Treatments	45
-Growth Performance Measurements	46
-Carcass Measurements	46
-Pork Fat Analysis	47
-Statistical Analysis	48
Results and Discussion	48
-Growth Performance	48
-Carcass Characteristics	51
-Fatty Acid Composition and IV of Backfat and Belly Fat	53
-Objective and Subjective Fat Color Scores	58
<b>Chapter 3. Effects of adding supplemental tallow to diets containing DDGS on fatty acid digestibility in growing pigs</b>	71
Overview	72
Introduction	73
Materials and Methods	75
-Animals and Housing	75
-Cannulation Procedure	75
-Dietary Treatments and Feeding	76
-Sample Collection and Chemical Analysis	77

-Calculations and Statistical Analysis	78
Results and Discussion	79
-Fecal Digestibility	79
-Ileal Digestibility	83
<b>Chapter 4. Summary</b>	<b>101</b>
<b>Literature Cited</b>	<b>103</b>

## List of Tables

<b>Table No.</b>	<b>Chapter 1.</b>	<b>Page No.</b>
1.1	Nutrient content of DDGS and Corn	3
1.2	Typical fatty acids found in swine diets and tissue depots	13
1.3	Fatty acid content and iodine value of select feed ingredients	15
1.4	Comparison of common fats and oils for swine diets	24
1.5	Ileal digestibility of select fatty acids in control diets and diets containing animal fat	33
<b>Chapter 2.</b>		
2.1	Ingredient composition, as is	61
2.2	Fatty acid profile of ingredients, as is, % fatty acids in product	62
2.3	Composition of diets (as-fed basis)	63
2.4	Nutrient composition of diets (as-fed basis)	64
2.5	Effects of tallow and DDGS on pig growth performance	65
2.6	Effects of tallow and DDGS on carcass characteristics	66
2.7	Effects of tallow and DDGS on belly characteristics	67
2.8	Effects of tallow and DDGS on belly and backfat fatty acid composition	68
2.9	Correlation of belly fat and backfat IV with diet IV	69
2.10	Effects of tallow and DDGS on belly and backfat color characteristics	70
<b>Chapter 3.</b>		
3.1	Fatty acid profile of DDGS and tallow, as-fed basis	95
3.2	Ingredient composition of diets, as-fed basis	96
3.3	Nutrient composition of diets, as-fed basis	97
3.4	Analyzed fatty acid composition of the diet, fecal and apparent ileal digestibility as influenced by dietary level of DDGS and tallow, expressed as a % of total dietary fat, and percentage of apparent ileal digestible dietary fatty acids	98

## List of Figures

<b>Figure No.</b>	<b>Chapter 1.</b>	<b>Page No.</b>
1.1	Ethanol production in the US	1
1.2	Inclusion of DDGS in poultry and swine diets	2
1.3	Classification of carbohydrates	6
1.4	Microorganism concentrations in the GIT of pigs	8
1.5	Simple and mixed triglycerides	10
1.6	Lipid conversion, transport, and absorption	18
1.7	Origin of lipids in adipose tissue	19
1.8	Influence of age on fatty acid composition and adipocyte size	21

## CHAPTER 1

### LITERATURE REVIEW

#### Introduction

With the current record high feed prices in the United States, pork producers are constantly seeking low-cost alternatives to conventional feed ingredients. Within the past decade, the United States has experienced a rapid growth in corn ethanol production (Figure 1.1).

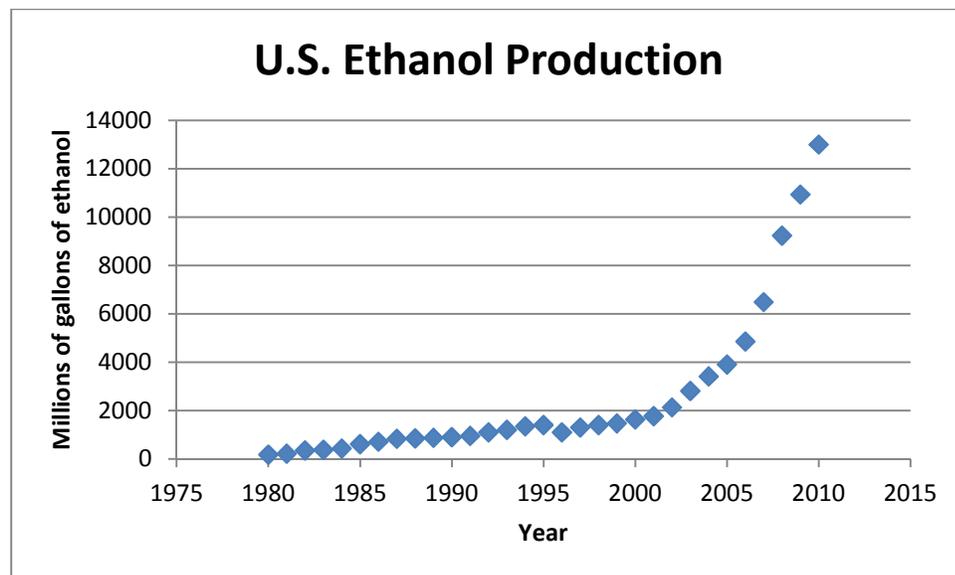


Figure 1.1 Ethanol production in the US (Adapted from RFA, 2011).

Low corn prices and low transportation costs allowed the corn-based ethanol industry to gain momentum and grow. Today, the ethanol industry has extended out of the Midwest and stretches from California to North Carolina. In 2009, the United States produced nearly 41,640 million liters of ethanol with production expected to increase to 49,210 million liters in 2010 (RFA, 2011).

With every gallon of ethanol produced, approximately 5.7 pounds of distillers

grains are produced (RFA, 2011). In 2010, the United States ethanol industry produced 32.5 million metric tons of distillers grains for livestock markets across the globe; of this amount, 61% was further processed and dried while the remaining 39% was marketed as wet distillers grains for use in cattle feeds (RFA, 2011). Both ample supply of DDGS and its competitive price compared to other ingredients result in a readily available and economically feasible ingredient for livestock producers. It is estimated that the majority of distillers grains is fed to beef and dairy cattle (80%) while 10% is fed to swine and 9% fed to poultry (RFA, 2011). Like the ethanol industry, the use of dried distiller’s grains with solubles (DDGS) has also exponentially increased in the poultry and swine sectors (Figure 1.2).

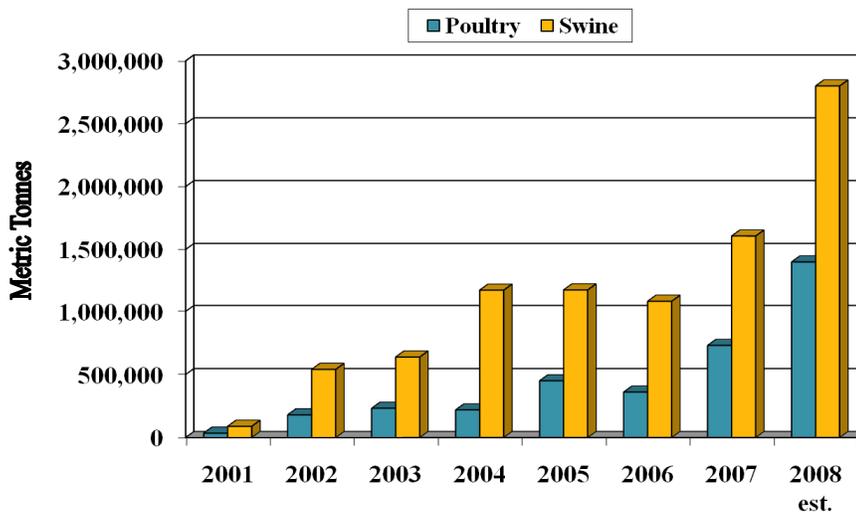


Figure 1.2 Inclusion of DDGS in poultry and swine diets (Shurson, 2009)

Currently, swine producers widely accept DDGS as a feed ingredient for all phases of production. Due to feed ingredient price volatility, distillers dried grains with solubles (DDGS) has become the most popular alternative feed ingredient in swine diets.

It is often added to grower-finisher diets at a rate ranging from 10 to 20% without reducing pig performance, while still capturing the economic advantages DDGS offers. During times of high corn and soybean meal prices relative to DDGS price, DDGS may be used at high levels (> 40%) in some grower-finisher diets. These cost savings are a result of partially replacing corn, soybean meal, and inorganic phosphorus (Whitney et al., 2006) in swine diets. However, not all DDGS sources are the same. Much variability in nutrient content of DDGS exists within and among ethanol plants.

The metabolizable energy (ME) content of DDGS is very similar to corn. According to the National Swine Nutrition Guide (2010), corn has a ME of 3,421 kcal/kg while DDGS has an ME of 3,414 kcal/kg. However, subsequent research has determined that the average ME of DDGS ranges from 3,750 to 3,900 kcal/kg of DM (Pedersen et al., 2007). Although the two feedstuffs are similar in terms of energy, they differ quite substantially in the composition of other macro nutrients. In particular, DDGS contains roughly three times more fat, fiber, and crude protein compared to corn as shown in Table 1.1.

Table 1.1 Nutrient content of DDGS and corn, as-fed

	DDGS			Corn		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Crude Fat, %	8.8	9.8	11.2	2.6	3.2	3.4
NDF, %	29.4	33.3	36.5	7.2	8.9	10.8
ADF, %	9.6	11.6	12.7	2.8	3.3	4.5
Crude Protein, %	27.3	29.1	31.9	10.0	10.8	12.8

Adapted from Urriola, (2007) and Ridley et al. (2002)

Nutrient composition varies within and among various ethanol plants in the upper Midwest (Spiehs et al., 2002). The fat content of DDGS can range from 8.8 to 12.4% (Shurson and Alghamdi, 2008). However, DDGS are consistently high in unsaturated

fatty acids, and nearly 80% of fatty acids in DDGS are unsaturated (Xu et al., 2010b). Xu et al. (2010b) found that DDGS contains high concentrations of the unsaturated fatty acids including: oleic acid and linoleic acid, 25.70, and 55.35%, respectively. Surprisingly, the linoleic acid content of DDGS is quite similar to the fatty acid proportions found in corn oil and soybean oil. Based on NRC (1998) estimates, corn oil contains 59.6% linoleic acid while soybean oil contains 51.0% linoleic acid. However, little is known regarding the digestibility of fatty acids in DDGS.

Results from many studies agree that feeding high levels of DDGS increases the incidence of soft pork fat (Xu et al., 2010b, Ulery et al., 2010, Benz et al., 2008). Soft pork fat is a major concern for pork processors because it creates challenges associated with processing and fabrication, processing yields, shelf-life, product attractiveness, and acceptability in certain export markets. Furthermore, as the dietary level of DDGS increases, the iodine value (IV), a measure of the degree of unsaturation, and level of polyunsaturated fatty acids (PUFA) in pork adipose tissue increases.

It is well documented that pork fat quality is negatively impacted by feeding DDGS (Widmer et al., 2008; Xu et al, 2010b). Distillers grains contains nearly 60% linoleic acid which, is one of the most prevalent polyunsaturated fatty acids (PUFA) in pork fat (Xu et al., 2010b). Unsaturated fats are preferentially deposited in pork fat depots. Several alternative feeding strategies presently exist to prevent pork fat quality problems while feeding DDGS. Some of those include removing DDGS from the diet prior to harvest, feeding wheat and barley based diets, utilizing reduced-oil corn co-products, adding conjugated linoleic acid (CLA), adding crude glycerol, or formulating diets based on the iodine product value. However, not all of these strategies are readily

available nor are they economically feasible for pork producers. A review by Stein and Shurson (2009) reported that results from most research studies show that the addition of DDGS to growing-finishing pig diets does not change ADG, ADFI, or G:F compared to when traditional corn-soybean meal diets are fed. Additionally, loin depth, backfat depth, and percentage carcass lean largely remain unchanged due to the addition of DDGS to growing finishing pig diets. However, effects of feeding DDGS diets on carcass yield have resulted in inconsistent responses.

Beef tallow is a readily-available fat source that is high in saturated fatty acids compared to other common animal fat sources. Pork fat firmness may be improved by adding a saturated fat source to grower-finisher swine diets. However, no research studies have been conducted to investigate the effects of adding supplemental tallow to diets containing high levels of corn DDGS diets on growth performance, carcass characteristics, pork fat quality, and fatty acid digestibility.

## **Understanding Fiber Utilization in Pigs**

### *What is Fiber?*

Carbohydrates are comprised of a variety of chemical compounds including: cellulose, hemicelluloses, lignin, pectin, and gums. Carbohydrates represent approximately 55-70% of the dry matter in swine diets (He, 2004). This broad and complex category of carbohydrates encompasses many different carbohydrate measures such as crude fiber, acid detergent fiber (ADF), neutral detergent fiber (NDF), and more as illustrated in Figure 1.3.

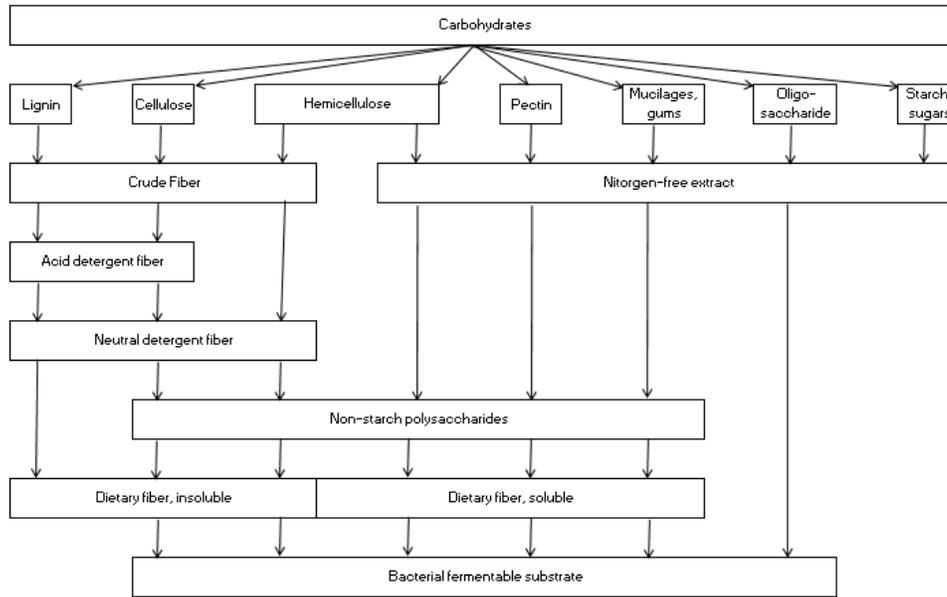


Figure 1.3 Classification of carbohydrates (adapted from He, 2004)

Dietary fiber is defined as the sum of plant polysaccharides and lignin that are not hydrolyzed by endogenous enzymes of the mammalian digestive system (Wenk, 2001). Often dietary fiber is regarded as having very low digestible and metabolizable energy content. The physiochemical properties of fiber, including its water-holding capacity, cation-exchange capacity, absorption, and gel-forming properties are dependent on factors such as the age and weight of the pig, chemical properties of the fiber, dietary concentration, feeding time, and transit time in the gut (Dierick et al., 1989). Fiber can influence transit times and may reduce the digestibility of certain nutrients such as minerals, and reduces energy digestibility (Wenk, 2001). The addition of fiber to pig diets can increase the microbial population in the gastrointestinal tract (GIT) which synthesizes volatile fatty acids (VFA) that can subsequently be absorbed by the pig (Wenk, 2001). However, the most important physiological and nutritional effects of

fiber include increased feed intake due to a diluted energy concentration of the diet, increased output of pancreatic and biliary secretions, and a reduction in the absorption of certain minerals (Dierick et al., 1989). Different types of fiber have different effects on digestion in the pig, and affect satiation, transit time, and energy digestibility.

### *Fiber Digestion*

Fiber is a poorly understood dietary component in monogastric animals. Digestibility of fibrous feed ingredients is greatly influenced by both physical and chemical characteristics (Wilfart et al., 2007). Nutrient absorption is largely determined by the type of fiber (enzymatic vs. fermentation) and site (small intestine vs. large intestine) of digestion. Enzymatic digestion refers to degradation caused by endogenous enzymes in the small intestine, whereas fermentation of fiber is caused by bacteria in the large intestine. Typically, the small intestine is the site of enzymatic degradation whereas the large intestine is associated with fermentation. Intensive microbial degradation of fiber takes place in the lower ileum, cecum, and lower large intestine which is important for VFA production and utilization (Wenk, 2001).

Wilfart et al. (2007) studied the impact of three levels of dietary fiber on nutrient digestibility in growing pigs using diets consisting of low fiber, medium fiber, and high fiber utilizing 0%, 20%, and 40% wheat bran, respectively. Furthermore, the fat content of the diet was restricted to 2.4 to 2.5%. Pigs were cannulated at two sites, the duodendum and ileum, to account for differences in nutrient absorption. Wilfart and colleagues (2007) determined that apparent digestibility of most nutrients increased from the duodenum and beyond. A significant decrease in fecal digestibility of ether extract with increasing dietary fiber content (77.0 vs. 65.2%) was observed for the low fiber and

high fiber diets, respectively. This finding suggests a possible interaction between fat and fiber digestibility.

### *Hindgut Fermentation*

Energy from fibrous ingredients is supplied to the host animal from digestive enzymes in the intestinal tract or from volatile fatty acids (VFA) which are produced by anaerobic bacteria (Pond, 1987). In the large intestine, digestion of components such as dietary fiber, lipids with high melting points, and insoluble proteins is driven by microbial fermentation. *Bacteroides succinogenes* and *Ruminococcus flavefaciens* are two of the most abundant cellulolytic organisms found in growing pigs and adult animals (Varel, 1987). Furthermore, the number of cellulolytic bacteria in the pig's large intestine can increase with prolonged feeding of high fiber diets (Varel and Pond, 1985). In the pig, but not other species, micro-organisms are concentrated in the cecum and colon compared to other organs of the gastrointestinal tract (Figure 1.4).

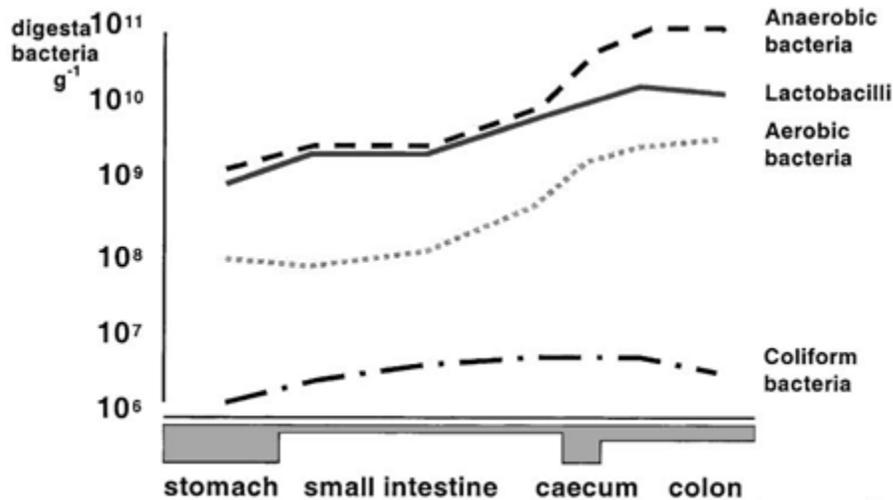


Figure 1.4 Microorganism concentrations in the GIT of pigs (Wenk, 2001)

Fermentation of dietary fiber results in the production of VFA, with a typical ratio

of 60% acetate, 25% propionate, and 15% butyrate (Grieshop et al., 2000). These VFA, which are rapidly absorbed, along with some vitamins, can contribute to the overall nutrient supply of the animal (Wenk, 2001). Typically, 5 to 28% of the maintenance energy requirement of a growing pig may be met by absorbed VFA (Pond, 1987; Grieshop et al., 2000). Dietary energy from microbial fermentation is suspected to be lower than that of carbohydrates which are absorbed as monosaccharides in the small intestine (Dierick et al., 1989). This is primarily due to the losses of methane, hydrogen, and heat resulting in a lower efficiency of metabolism (Dierick et al., 1989; Grieshop et al., 2000). Approximately, 6% of the energy value from each gram of carbohydrate digested in the hindgut of pigs is lost as heat during the fermentation process, and an additional 35-60% is lost as methane and heat during the conversion to VFA to body tissue (Dierick et al., 1989).

### **Understanding Lipid Utilization in Pigs**

Lipids are a very important class of nutrients required for numerous physiological and metabolic functions. Lipids have four main functions : 1) to supply energy for maintenance and productive functions; 2) serve as a source of essential fatty acids, which can only be supplied by the diet and serve as building blocks for hormones; 3) carry fat-soluble vitamins; and 4) act as an integral portion of cell membranes (Pond et al 1995). They contain nearly 2.25 times the amount of energy compared to carbohydrates or protein (4 calories/gram), thus providing a considerable amount of energy (9 calories/gram; Pond et al., 1995). All lipids share common characteristics: insoluble in water, yet soluble in organic solvents, contain long-chain hydrocarbons, and are present

or derived from living organisms. The lipid family includes several vital compounds including triglycerides, phospholipids, cholesterol, and fat soluble vitamins (Pettigrew and Moser, 1991). Furthermore, adding supplemental fat to diets can suppress dust, facilitate pelleting, and decrease wear on feed mixers (Patience and Thacker, 1989). However, including supplemental fat in swine diets also creates a few challenges including reduced diet flowability and challenges such as handling fat and mixing it with other ingredients (Pettigrew and Moser, 1991).

### *Types of Lipids*

There are several different types of lipids. Triglycerides serve as the main component of lipids; while minor components of lipids include mono- and diglycerides, free fatty acids (FFA), phospholipids, sterols, and pigments. In swine diets, the majority of lipids found in the diet are present as triglycerides. A triglyceride is comprised of three fatty acid molecules which are attached to a single glycerol molecule via an ester bond. Triglycerides can be either simple, where the fatty acids are identical, or mixed, where two or three fatty acids are different (Figure 1.5).

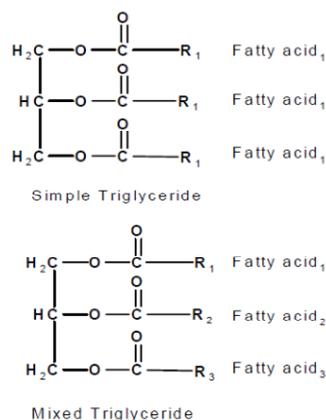


Figure 1.5 Simple and mixed triglycerides (adapted from Food Fats and Oils, 2006)

Mono- and diglycerides are the result of the normal digestion of triglycerides.

Free fatty acids (FFA) are fatty acids that are unattached from a triglyceride. Typical levels of FFA in refined fats and oils consist of less than 0.1% (Food Fats and Oils, 2006). Phospholipids contain either a glycerol or sphingosyl backbone, two fatty acids, and a phosphate group often with choline attached to its end. The hydrocarbon tails of the fatty acids are hydrophobic, but also hydrophilic due to the phosphate group. Therefore, phospholipids are soluble in both water and oil. Phospholipids are most commonly found in living cells and serve as a crucial part of the phospholipid bilayer of cell membranes. Most phospholipids are removed from oil during refining. Cholesterol is the primary animal fat sterol, whereas vegetable oil sterols are called phytosterols. The type and concentration of sterols varies based on the source and refinement of the lipid source. Several pigments are composed of lipids. For instance, carotenoids ranging from yellow to deep red occur naturally in many fats and oils. However, during processing, most pigments are removed to allow for acceptable color, flavor, and stability (Foods Fats and Oils, 2006).

#### *Fatty Acid Characteristics*

The physical and chemical characteristics of fatty acids in a lipid define its properties. One hundred grams of fat or oil will yield approximately 95 grams of fatty acids (Food Fats and Oils, 2006). Fatty acids are classified according to their degree of saturation. Saturated fatty acids contain only single carbon-to-carbon bonds and are the least reactive. Unsaturated fatty acids contain one or more carbon-to-carbon double bonds and are more reactive chemically compared to saturated fatty acids. As the number of double bonds of a fatty acid increases, so does its reactivity, thus increasing its chances of oxidation.

The melting point of fatty acids is dependent upon the degree of saturation and chain length (Pettigrew and Moser, 1991). In saturated fatty acids, melting point increases with chain length. Short-chain fatty acids have lower melting points than longer-chained fatty acids. Melting points of unsaturated fatty acids are greatly affected by the position and conformation of double bonds (Food Fat and Oils, 2006). For example, oleic acid (C18:1) and its geometric isomer, elaidic acid (C18:1-trans) have very different melting points. Oleic acid has a melting point of 16.3° C, while elaidic acid has a melting point of 43.7° C.

The chemical and physical properties of fatty acids are determined by the chain length and degree of saturation. For instance, lipids that are solid at room temperature usually contain saturated fatty acids with a chain length of 10 carbons or more and are called fat. Conversely, lipids that are liquid at room temperature and have less than 10 carbons are called oil (Pond et al., 1995). Finally, melting point and degree of saturation are inversely related. For example, as the level of unsaturation increases, the melting point decreases, thus resulting in a “softer” fat. Table 1.2 lists typical fatty acids found in swine diets and fat depots as well as the chain length and number of double bonds and melting point.

Table 1.2 Typical fatty acids found in swine diets and tissue depots

Fatty Acid	Chain length	Melting Point, °C
Caprylic	C 8:0	16.5
Capric	C10:0	31.4
Lauric	C12:0	44.0
Myristic	C14:0	58.0
Palmitic	C16:0	63.0
Palmitoleic	C16:1	1.5
Stearic	C18:0	71.5
Oleic	C18:1	16.3
Linoleic	C18:2	-5.0
Linolenic	C18:3	-11.3
Arachidic	C20:0	75.4
Arachidonic	C20:4	-49.5

Adapted from Azain (2001)

Medium-chain fatty acids have a chain length of 6 to 12 carbons. Long-chain fatty acids of 14 to 20 carbons are most abundant in swine diets and pork fat depots (Azain, 2001). The two most abundant fatty acid chain lengths in pig fat depots are 16 and 18 carbons. Palmitic acid (C16:0) is generally considered the end product of lipogenesis and accounts for approximately 20 to 30% of the fatty acids in pork adipose tissue. The other predominate fatty acids in pork fat depots are stearic (C18:0) and oleic acids (C18:1), which account for 10 to 15% and 40 to 50% of the fatty acids, respectively (Azain, 2001). In addition to being supplied in the diet, both stearic and oleic acids can be synthesized from palmitate by elongation and desaturation.

Although no dietary requirement for fat exists, certain fatty acids are required for proper growth and development. These required fatty acids are known as essential fatty acids (EFA) and include linoleic (C18:2), linolenic (C18:3), and arachidonic (C20:4) acids. It is important to note, however, that arachidonic acid can be synthesized from

linoleic acid (Pond et al., 1995). These EFA serve as an integral part of the lipid-protein structure of cell membranes, and play an important role in the structure of compounds known as eicosanoids that are involved in the regulation of hormone release from the hypothalamus and pituitary glands (Pond et al., 1995). Diets that are deficient in EFA result in scaly skin and necrosis of the tail, growth and reproductive failure, and edema (Pond et al., 1995).

### *Iodine Value*

Iodine value (IV) is a measure of the degree of unsaturation in fat. It is a measurement of the mass of iodine, in grams, that is absorbed by 100 grams of an unsaturated fat. Values for IV can either be calculated or determined in a laboratory. In the lab, an iodine solution reacts with the double bonds of an unsaturated fat and is determined by titration. Higher IV values indicate that a fat contains more double bonds. Routinely, the IV is commonly calculated based on the fatty acid profile utilizing the following equation (AOCS, 1998):

$$\text{IV} = \text{C16:1} \times 0.95 + (\text{C18:1} \times 0.86) + (\text{C18:2} \times 1.732) + \\ (\text{C18:3} \times 2.616) + (\text{C20:1} \times 0.785) + (\text{C22:1} \times 0.723)$$

The IV calculation emphasizes the amount of C18:2 and C18:3. Ultimately, sources rich in both fatty acids have greater IV as demonstrated in Table 1.3.

Table 1.3 Crude fat, fatty acid content, and iodine value of selected feed ingredients

Feed stuff	Crude fat, %	C14:0	C16:0	C18:0	C18:1	C18:2	C18:3	IV
Barley	3.5	0.2	19.8	0.7	10.4	44.2	4.5	129
Soybean meal	3.1	0.4	18.3	4.2	15.9	51.8	6.8	137
Animal Fat	99.9	1.8	23.6	13.3	38.8	6.0	0.5	57
Soybean oil	99.9	-	10.0	2.0	29.0	51.0	7.0	140
Corn oil	99.9	0.1	10.4	1.6	30.7	54.6	1.7	127
Palm oil	99.9	12.0	8.3	2.2	23.6	4.0	0.1	29
Coconut fat	99.9	-	9.0	5.0	8.0	3.0	-	10

Adapted from Madsen et al. (1992)

#### *Iodine Value Product*

One way to minimize high IV in pork carcass fat depots is to formulate diets based on an iodine value product (IVP) basis. The IVP is a tool to help estimate the IV in the diet based on IV levels of specific ingredients containing fats or oils in order to minimize the risk of exceeding the desired IV in pork fat depots. The IVP and IV are closely related. As the IVP of a diet increases, so also does the IV of the backfat (Madsen et al, 1992). The IVP can be calculated as follows (Madsen et al., 1992):

$$\text{IVP} = \text{percentage of dietary fat in diet} \times \text{iodine value of fat source} \times 0.1$$

#### *Fat Digestion and Absorption*

Dietary triglycerides are hydrolyzed to 2-monoglycerides and free fatty acids in the intestinal tract. The upper portion of the small intestine is the site of fatty acid absorption. Bile is necessary for solubilization of dietary lipid and eventual absorption of fat and fat-soluble vitamins.

Bile is produced by hepatocytes and is stored in the gall bladder. Bile is composed of Na, K, Cl, bicarbonate, and several other organic components (bile salts,

phospholipids, cholesterol, mucus, and bile pigments; Yen, 2001a). Bile salts aid in the emulsification of fat and facilitate absorption by conjugating with the amino acids glycine or taurine (Yen, 2001a). Bile acids are reabsorbed in the lower small intestine and transported by the portal vein to the liver where they are recycled into bile again (Yen, 2001a). The recirculation of bile components provides a means for coping with demand, because daily bile use by the pig far exceeds its capacity for synthesis (Yen, 2001a). Bile secretion responds to dietary changes in pigs. For example, when dietary fat content was increased from a low (2%) to a medium (10%) level, the secretion of bile acids increased dramatically, whereas bile phospholipids and cholesterol rose moderately (Juste et al, 1983). However, when dietary fat content was raised to a high concentration (20%), bile acid output did not increase further, but additional increases in output of phospholipids and cholesterol were observed (Juste et al., 1983). Bile secretion by the hepatocytes in pigs is continuous, but can be increased by the presence of bile salts, secretin, or cholecystokinin in the blood (Kidder and Manners, 1978). However, for fat digestion, bile is only needed intermittently. When fat content of diets rose from 2% to 10%, the secretion rate of bile acids increased dramatically (Juste, 1983). However, increasing the dietary fat content to 20% does not cause bile output to increase further, but rather, it reaches a plateau.

In order for digestion and absorption to occur, triglycerides must be broken down by bile and pancreatic lipases through a process known as emulsification. Emulsification occurs and greatly reduces the particle size of lipids from 500 to 1000  $\mu\text{m}$  (Pond et al., 1995). With smaller particle size, greater surface area is exposed for pancreatic and intestinal lipases. Lipase works to remove the outer two fatty acids from each triglyceride

molecule resulting in one beta-monoglyceride and two FFA (Yen, 2001a). Micelles or small, spherical aggregates form to contain the FFA, beta-monoglycerides, phospholipids, and cholesterols. Micelles are aggregates of mixed lipids and bile acids suspended within the digesta. Micelles are arranged so that the interior of the micelle is filled with the hydrophobic fatty acid tails. Eventually, the micelles reach and contact the brush border of the small intestinal enterocytes where lipids are absorbed into the mucosal cells and bile salts are recycled. Monoglycerides and FFA move out of the micelles via diffusion into the enterocyte.

The proximal jejunum is the main site of absorption for lipids, but some absorption does occur from the distal duodenum to the distal ileum (Pond et al., 1995; Yen, 2001a). Glycerol and short-chain fatty acids are absorbed by passive transport. Short-chain fatty acids pass directly to the portal blood system. Micelles diffuse through the gut lumen to the brush border of the mucosal cells and allow monoglycerides and fatty acids to diffuse across the apical membrane of the enterocyte (Yen, 2001a). As depicted in Figure 1.6, long-chain fatty acids are converted to derivatives of coenzyme A in the presence of ATP; the complex of fatty acyl-coenzyme A reacts with monoglyceride within the epithelial cell to form di- and then triglycerides (Pond et al., 1995). Next, chylomicrons are formed where a thin layer of protein coats the lipid droplet surface and consists mainly of triglycerides with small quantities of phospholipids, cholesterol ester, and protein. Chylomicrons are transported to the lymph system and, eventually, to the blood system.

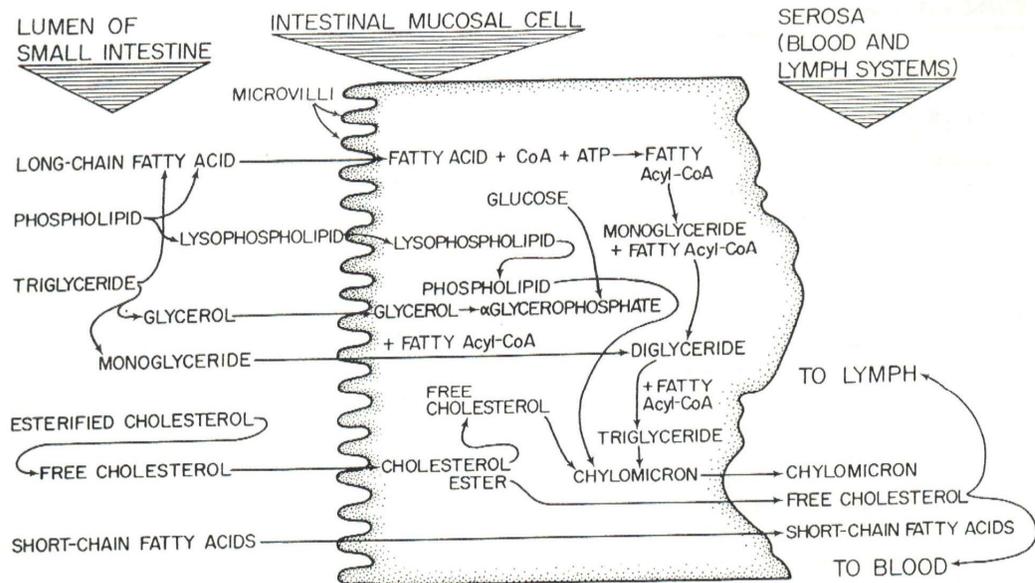


Figure 1.6 Lipid conversion, transport, and absorption (Pond et al., 1995)

Lipids found in the blood can be classified into four groups that vary in density and composition: chylomicrons, very low-density lipoproteins (VLDL), low-density lipoproteins (LDL), and high-density lipoproteins (HDL). The liver, fat depots, and other tissues rapidly remove chylomicrons and other lipids from the blood.

Chain length of the fatty acid determines preferential digestibility in pigs. Short-chain fatty acids (SCFA) are the end products of bacterial fermentation. Volatile fatty acids (VFA) such as acetate, butyrate, and propionate are the main SCFA. Feeding fibrous feedstuffs greatly increases the concentration of SCFA in the colon which can be used as an energy source to the pig for hindgut fermentation (Wang et al., 2004; Anguita et al., 2006). Medium-chain fatty acids from coconut oil have a higher apparent digestibility compared to the long-chain fatty acids found in corn oil or tallow (Cera et al., 1989). Medium-chain fatty acids are liberated preferentially in the case of mixed triglycerides (Bach and Babayan, 1982). Furthermore, Cera et al. (1988) reported that

long-chain unsaturated fatty acids are hydrolyzed and absorbed at higher rates than those fatty acids with a higher degree of saturation. Likewise, digestibility of fat seems to reach a plateau three weeks following weaning of pigs at 21 d of age (Cera et al., 1988).

### *Fat Deposition*

The primary storage site for triglycerides is in adipose tissue or depot fat since it is readily capable of oxidizing fatty acids and synthesizing fat from dietary carbohydrates and dietary fat (Figure 1.7).

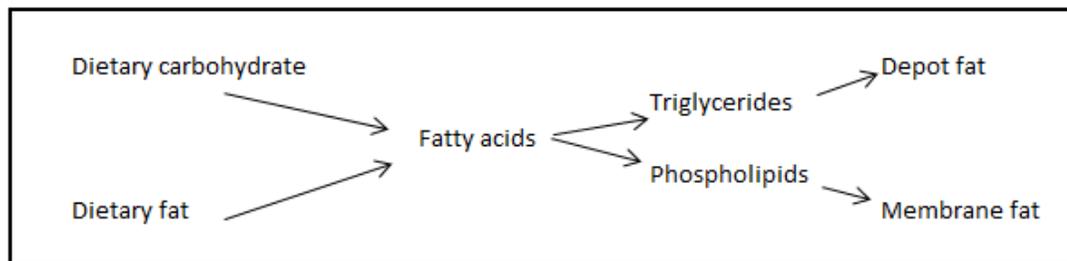


Figure 1.7 Origin of lipids in adipose tissue (Adapted from Schinckel et al., 2002)

*De novo* synthesis forms triglycerides which are deposited into depot fat, and phospholipids which serve as critical building blocks for cell membranes. However, the contribution from each source is highly dependent on the amount of fat in the diet (Schinckel et al., 2002). The depot fat of nonruminant animals strongly mimics the fatty acid profile of the diet (Pond et al 1995, Babatunde et al 1967). Conversely, depot fat in ruminants does not typically resemble dietary fat intake due to biohydrogenation of fat by the rumen microflora.

Fat deposition is the continual accretion of lipids in adipose tissue and occurs continuously. Adipocyte size and number relate to adipose tissue development. Adipose tissue contains approximately 70-90% lipid, 5-20% water, and approximately 5%

connective tissue. The number of adipocytes is predetermined and associated with late gestation and the pre-weaning period, whereas adipocyte size is related to the post-weaning to finishing period (Azain, 2004). Subcutaneous fat depots are the most important site of fat deposition. Several factors influence fatty acid composition in adipose tissue including: diet, fatness, age, gender, breed, environmental temperature, and depot sites.

Diet composition easily affects the fatty acid composition in various tissues including fat depots and skeletal muscle (Koch et al., 1968, Brooks, 1971; Nurnberg et al., 1998). It is estimated that a diet low in fat (3 to 4%) contributes 80% of deposited triglycerides derived from corn or barley-based diets (Schinckel et al., 2002). Dietary linoleic acid is preferentially deposited in fat depots (Koch, 1968). Pork fat containing greater than 14% linoleic acid (C18:2) is associated with soft fat (Rentfrow et al., 2003). Linoleic acid is not synthesized by the pig, nor is it significantly modified prior to deposition (Ellis and McKeith, 1999). It is documented that the level of saturated fat in pork fat can be altered by inclusion of unsaturated fat in the diet (Rentfrow et al. 2003).

Leaner pigs have a greater concentration of linoleic acid in their fat depots because a greater proportion of fatty acids are derived from the diet rather than from *de novo* synthesis (Ellis and McKeith, 1999; Nurnberg et al., 1998). Pigs are born with approximately 2% body fat. As the age of pigs increases, the amount of adipose tissue increases (Figure 1.8). Adipocyte diameter rapidly increases from 100 to 180 days of age. After 180 days of age, little change is observed in adipocyte size. The percentage of unsaturated fatty acids decreases with growth up to 180 days, while the percentage of saturated fatty acids increases during this timeframe. Furthermore, the fatty acid profile

changes during growth (Nurnberg et al., 1998; Kloareg et al., 2007).

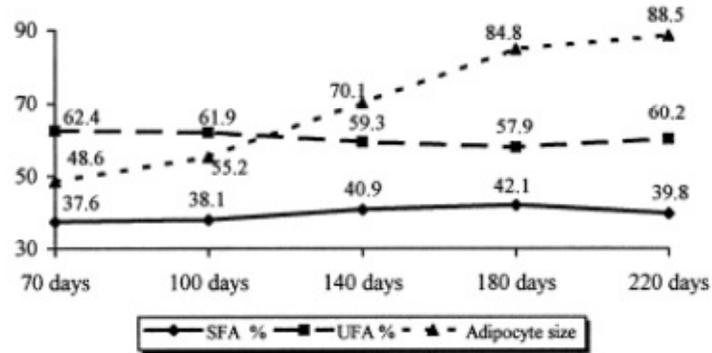


Figure 1.8 Influence of age on fatty acid composition and adipocyte size (Adapted from Nurnberg et al., 1998)

At equal slaughter weights, intact males are leaner than gilts, and gilts are leaner than barrows. Barrows deposit more saturated fatty acids compared to gilts (Koch et al., 1968; Nurnberg et al., 1998). Genetics play an integral role in fat composition. Intramuscular fat is highly heritable with  $h^2$  between 0.4 to 0.6 (Nurnberg et al., 1998). Housing pigs above their thermoneutral zone and decreasing spatial allocation increases iodine value in belly and backfat and decreases the saturated to unsaturated fatty acid ratio (White et al., 2008). Koch et al. (1968) concluded that the inner layer of backfat undergoes a more rapid change in composition compared to the middle or outer layers.

#### *Regulation of Fat Deposition*

If energy demands of the pig are being met, excess energy is stored in adipose tissue. Regulation of fat deposition is dependent on the energy status of the animal. The addition of dietary fat has been shown to inhibit *de novo* fatty acid synthesis in rats, poultry, and pigs (Herzberg and Rogerson, 1988; Clarke, 2001). In rats and poultry, polyunsaturated fatty acids have a greater ability to inhibit *de novo* lipogenesis compared

to saturated fatty acids. However, in pigs these same effects of polyunsaturated fatty acids are not observed (Smith et al., 1996).

Adipose tissue produces a variety of hormones. Leptin is one hormone produced by adipose tissue and has been shown to affect feeding behavior, animal health, and reproduction (Ramsey, 2003). Leptin can indirectly inhibit glucose conversion to lipid and directly inhibit lipogenesis in porcine adipocytes (Ramsay, 2003; Hausman et al., 2009). Furthermore, leptin functions to promote the partitioning of energy away from lipid accretion within porcine adipose tissue, in part, by decreasing insulin-mediated stimulation of lipogenesis by reducing fatty acid utilization (Ramsay, 2003).

Unlike other mammals, adipose tissue in pigs is the main organ for fatty acid synthesis (Duran-Montge et al., 2009). The dietary effects of various fats are tissue specific and have been linked to the modification of mRNA abundance of genes for encoding lipogenic enzymes (Duran-Montge et al., 2009).

#### *Fatty Acid Digestibility*

No results have been published on the digestibility of fatty acids of diets containing DDGS. However, Stein (2009) determined that the apparent ileal digestibility of acid-hydrolyzed ether extract (AEE) in DDGS and showed that it tended to increase as the concentration of DDGS increased in the diet. However, in comparison to other ingredients, the AEE digestibility of DDGS was rather low, ranging from 51.5 to 60.1%. Very few studies have determined fatty acid digestibility in pigs. Most fatty acid digestibility research deals with digestibility of various fats and oils rather than grain-based energy ingredients like corn or soybean meal. Ozimek et al. (1984) determined ileal and fecal digestibility of diets that contained either 10% beef tallow or rapeseed oil.

Apparent fecal digestibilities of saturated fatty acids were lower than corresponding ileal digestibilities (Ozimek et al., 1984, Duran-Montgé et al., 2007). However, Duran-Montgé et al. (2007) determined that unsaturated fatty acid digestibility was lower in the ileal digesta and greater in the feces. Saturated fatty acid digestibility is lower than unsaturated fatty acid digestibility irrespective of whether it was determined in feces or ileal digesta (Ozimek et al., 1984).

Crude fat ileal digestibility was lower in diets supplemented with tallow compared to other fat sources including high oleic sunflower oil, sunflower oil, linseed oil, and a fat blend containing tallow, sunflower oil, and linseed oil (Duran-Montgé et al., 2007). Apparent fecal digestibility of saturated fatty acids was greater in tallow containing diets compared to oil-supplemented diets, and apparent fecal digestibility of polyunsaturated fatty acids was higher in oil-supplemented diets than in animal fat diets (Duran-Montgé et al., 2007). Apparent fecal digestibility of stearic acid was negative in oil-supplemented diets, but positive for diets containing animal fat, which suggests that microflora could increase stearic acid concentrations in feces at the expense of PUFA (Duran-Montgé et al., 2007). Apparent ileal digestibility of the sum of fatty acids and saturated fatty acids was lower for tallow containing diets even though the diet contained a high concentration of these fatty acids (Duran-Montgé et al., 2007).

#### *Fat Sources and Types*

Numerous fat sources from animal and plant origin exist for use in monogastric animal diets. The most common animal fats used in the swine industry include beef tallow, choice white grease, and poultry fat. Additionally, producers often include vegetable based oils, including corn oil, soybean oil, and canola oil in swine diets. Of

these common dietary fats, their fatty acid composition varies greatly as depicted in Table 1.4. Of the common fats and oils added to swine diets, oils have a greater concentration of unsaturated fatty acids as well as higher iodine values than animal fats. Conversely, beef tallow has the greatest amount of saturated fatty acids and the lowest iodine value.

Table 1.4 Comparison of common fats and oils for use swine diets

Source	Unsaturated fatty acids, %	Saturated fatty acids%	Iodine Value
Beef Tallow	47.9	52.1	44
Choice White Grease	59.2	40.8	60
Poultry Fat	68.8	31.2	78
Corn Oil	86.7	13.3	125
Soybean Oil	84.9	15.1	130
Canola Oil	92.6	7.4	118

Adapted from NRC (1998)

#### *Benefits of Supplemental Fats in Swine Diets*

Fat is typically added to swine diets to serve as a source of energy. One of the main benefits of including supplemental fat sources in swine diets is to improve growth performance. Fat addition results in reduced feed intake, increased average daily gain and improved feed efficiency (Azain, 2004). Dust reduction is a secondary benefit associated with dietary fat inclusion. Diet palatability is improved with supplemental fat, and fat plays an integral role in meat palatability.

#### *Methods to Evaluate Fat Content*

Many different types of analytical procedures exist for fat (ether extract) analysis. Different solvents are used on different substrates. Unfortunately, accurate and precise results can be difficult to achieve because of the myriad of laboratory procedures available. Furthermore, laboratory to laboratory and technician to technician error exists

and affects the accuracy of results. For feedstuffs, ether extraction is the classical method for lipid determination (Palmquist and Jenkins, 2004). The official AOAC method (920.39) indicates that the solvent should be diethyl ether, yet it is often substituted with petroleum ether or hexane which may influence completeness of extraction (Palmquist and Jenkins, 2004). Hexanes are less polar and therefore, extract less membrane lipid and yield a lower analyzed value. Acid-ether extraction is another technique used for oil recovery. Generally, fatty acid analysis with the acid extraction procedure yields higher values than without acid treatment, and this increase may be attributed to the increased extraction of lactic acid (Palmquist and Jenkins, 2004). For tissues of animal origin, the Folch method is commonly employed for lipid extraction (Folch et al., 1958). Other procedures have been proposed by Bligh and Dryer (1959) and Sheppard (1963), which use varying concentrations of chloroform:methanol or ethanol:ether solutions, respectively.

#### *Fat Source Quality*

Fat quality is often characterized by five main measures: composition, titer, color, impurities, and stability (Azain, 2001). Composition of fat generally refers to the fatty acid profile, particularly total fatty acids and free fatty acid content (Azain, 2001). Titer, or fat hardness, measures the temperature (in degrees Celsius) where a fat sample solidifies, and it is inversely related to iodine value (Azain, 2001). The color of fat is indirectly related to nutritional quality, but it can be an indicator of the composition of the fat source. Impurities of fat sources are measured on the MIU (moisture, impurities and unsaponifiables) index. No nutritional values are associated with MIU, however it can include contaminants such as hair, bone, soil, or plastic. Stability can be measured by

lipid oxidation tests such as peroxide value, thiobarbituric acid (TBA) test, and active oxygen method (AOM). The peroxide value measures the rancidity of a sample from the concentration of peroxides and hydroperoxides formed in the initial stages of lipid oxidation (Azain 2001; DeRouche et al., 2004). However, peroxide values may be misleading depending on the thermal and oxidative exposure the fat has undergone (DeRouche et al., 2004). Additionally, high peroxide values indicate rancid fat, whereas moderate values may indicate depletion of peroxides after reaching high concentrations. The TBA test is a popular and commonly used method to detect rancidity due to lipid oxidation (Rosmini et al., 1996). The TBA test detects aldehydes that are produced in the termination phase of lipid oxidation with 2-thiobarbituric acid. A spectrophotometer is used to measure the red color resulting from the reaction. Similar to peroxide value, this method may be misleading because aldehydes may not have formed or may have been lost during processing and storage. Finally, the AOM predicts stability of a fat by bubbling air through a fat solution and is defined as the number of hours required for the peroxide concentration to reach 100 meq/kg of fat. Unstable fats reach this peak quickly. Unfortunately, this method is very time-consuming. Other factors including the digestibility of the dietary fat, daily quantity of ME and fat consumed, and environmental temperature influence the nutritional value of fat as an energy source (Stahly, 1984).

### ***DDGS as a Feed Ingredient in Swine Diets***

#### ***Growth Performance and DDGS***

Much research suggests that feeding levels up to 20% of DDGS maintains growth performance in grower-finisher pigs. Several reports show that average daily gain is

maintained or improved when feeding less than 20% DDGS (Gralapp et al., 2002, Widyaratne and Zijlstra 2007; Widmer et al., 2008). However, a few studies have shown that a decrease in ADG occurs when feeding up to 30% DDGS (Whitney et al., 2006; Benz et al., 2007; Linneen et al., 2008).

Average daily feed intake follows a similar pattern to ADG and it typically remains unchanged compared to feeding conventional corn-soybean containing diets (Stein and Shurson, 2009). Conversely, reductions in ADFI have been documented when dietary levels of DDGS increased from 0 to 20% (Benz et al., 2007; Linneen et al., 2008). Feed consumption may be decreased due to the reduced palatability of DDGS from some sources because pigs prefer a corn-soy based diet over one containing DDGS (Hastad et al., 2005a).

Feed efficiency largely remains unchanged with incorporation of DDGS in the diet (Stein and Shurson, 2009). However, in certain circumstances, feed efficiency has been shown to decline with increasing levels of DDGS in the diet (Whitney et al., 2006), whereas Benz et al. (2007) found that pigs fed 5% DDGS tended to have improved feed efficiency.

#### *Effects of Feeding DDGS Diets on Carcass Characteristics*

In general, carcass characteristic responses from feeding diets containing DDGS are consistent where no change in backfat depth, loin depth, and percentage carcass lean are observed compared to feeding corn-soybean meal diets to growing-finishing pigs. Furthermore, characteristics such as hot carcass weight, backfat thickness, and loin depth are usually not altered with the addition of DDGS (Widmer et al., 2008, Stein and Shurson, 2009). However, for each of these carcass parameters, a few studies have shown

a reduction in final body weight (Leick et al., 2010), carcass weight (Linneen et al., 2008, Whitney et al., 2006) and yield (Linneen et al., 2008) when 30% DDGS was included in the diet. Similarly, backfat and fat-free lean index tended to decrease with increasing levels of DDGS in the diet (Linneen et al., 2008).

Effects on dressing percentage is the most inconsistent response when feeding diets containing up to 30% DDGS. In some instances, dressing percentage is reduced (Cook et al, 2005; Whitney et al., 2006; Beltranena et al., 2009), whereas other researchers have not detected significant changes (Linneen et al., 2008; Widmer et al., 2008). The reason for this inconsistent response is not clear.

#### *DDGS Effects on Pork Fat Quality*

According to Wood et al. (1989), animal adipose tissue quality is affected by changes in the proportions of lipids, water, and connective tissue during growth. As animals age, the rate of fat accretion also increases due to a lower proportion of water and a greater proportion of lipid. High quality pork fat must have less than 15% polyunsaturated fatty acids and more than 15% stearic acid (NPPC, 2000). Additionally, the IV of pork fat should be less than 70 (NPPC, 2000).

Soft pork fat is typically characterized as having a high proportion of unsaturated fatty acids, specifically, linoleic acid (Wood et al., 1989; Maw et al, 2003). Soft fat is influenced by many different variables, yet it is directly proportional to the unsaturated fatty acid composition of the diet. Several challenges are related to soft fat. Soft pork fat is a major concern for the pork processors because it can cause significant problems during cutting, grinding, and slicing operations (Ellis and McKeith, 1999). Belly firmness is perhaps the most notable fat quality concern because soft bellies result in

bacon slicing difficulties (Schinckel et al., 2002). Additionally, lower processing yields and reduced value may result due to complications with soft fat (Ellis and McKeith, 1999).

Distiller's grains with solubles have quite a profound effect on pork fat quality. Several researchers have demonstrated that including high levels of DDGS (> 25%) in grower-finisher diets decreases the quality of pork fat. According to Leick et al. (2010), feeding an increasing dietary level of DDGS led to a decrease in belly firmness as measured by the belly flop test where the distance from skin to skin was measured when the belly was draped skin-side down on a stainless-steel rod. Similarly, Xu et al. (2010b), Widmer et al. (2008), Whitney et al. (2006) found similar responses when feeding increasing levels of DDGS. Because DDGS contains a high proportion of polyunsaturated fatty acids compared to saturated fatty acids, soft pork fat is generally the result. White et al. (2009) demonstrated that IV in back and belly fat increased while feeding DDGS. Benz et al. (2007), confirmed that backfat, jowl fat, and belly fat IV increased linearly with increasing dietary levels of DDGS.

The fatty acid composition of pork fat is a reflection of the fatty acid composition of the diet. Benz et al. (2007) determined that C18:2 (linoleic acid) increased linearly in backfat, jowl fat, and belly fat depots with increases in DDGS from 0 to 20%, while saturated fatty acid levels linearly decreased in pork fat depots .

Fat color scores are also affected by inclusion of DDGS in swine growing-finishing diets. Lightness (L\*) decreases in belly fat depots when DDGS inclusion rates increase (Widmer et al., 2008; Leick et al., 2010). Values for a\*, an indicator of redness, and b\*, an indicator of yellowness, as measured in fat depots remain unchanged with the

inclusion of DDGS (Widmer et al., 2008).

### *Pork Quality and DDGS*

Pork quality largely remains unchanged with inclusion of up to 30% DDGS in grower-finisher swine diets. Results from Leick et al. (2010) indicate that increasing dietary inclusion rates from 0, 15, 30, 45, or 60% DDGS had minimal effects on loin quality, but decreased belly quality, bacon characteristics, and fat stability. Conversely, cooking loss, shear force, bacon characteristics, and palatability were not affected by the inclusion of up to 20% DDGS (Whitney et al., 2006; Widmer et al., 2008; Xu et al., 2010a). Color characteristics of fresh ground pork shoulder and sausage as measured by a Hunter MiniScan are improved when 5 % tallow is included in diets containing 30% DDGS suggesting improved shelf life (Popowski et al., 2010). Feeding pigs 30% DDGS diets, with or without 5% tallow, did not impact bacon slicing yield or quality, but bacon from pigs fed DDGS had higher shatter scores compared to pigs fed corn-soybean meal diets indicating that fat in bacon had a “spider-web” consistency and is less desirable for consumers (LaBerge et al., 2011).

### *Strategies to Improve Pork Fat Quality when Feeding DDGS*

Several alternatives exist to improve pork fat quality when feeding DDGS diets. Removal of up to 30% DDGS from the diet for 21 to 30 d prior to harvest has been shown to be effective in improving pork fat quality (Hill et al., 2008; Beltranena et al., 2009; Xu et al., 2010a). Likewise, adding 0.6% conjugated linoleic acid to DDGS diets 10 to 30 d pre-harvest increases belly firmness and also improves fresh pork quality (Schinckel et al, 2000; White et al., 2007). Replacing DDGS with other corn co-

products, such as corn germ meal that have reduced oil content also improves pork fat quality (Widmer et al., 2008). Finally, swine diets can be formulated based on IVP. Emphasis should be placed on formulating grower-finisher swine diets using IVP in order to avoid pork carcasses with IV exceeding the recommended threshold (Madsen, 1992; Boyd 1997).

#### *CLA and Ractopamine*

Conjugated linoleic acid (CLA) refers to a group of positional and geometric isomers of linoleic acid (Eggert et al, 2001; White et al., 2009). Feeding CLA to pigs increases the proportion of saturated fatty acids and increases belly and backfat firmness (Ostrowska et al, 1999, Eggert et al., 2001; Dugan et al., 2004). Adding CLA decreased the IV of the outer backfat layer from 71 to 68 (White et al., 2009). Additionally, bacon leanness was reduced when 20% or more DDGS was included in the diet to finishing pigs; however, with the addition of 0.6% CLA, these effects were partially reversed (White et al., 2009).

Ractopamine is a beta adrenergic agonist that has been shown to increase growth rate and carcass leanness in pigs (Weber et al., 2006; Schinckel et al, 2010; Gerlemann et al, 2010). Additionally, feeding ractopamine decreased fatty acid synthesis in porcine adipose tissues (Mersmann, 1998), which may alter the fatty acid composition of fat depots. When feeding various levels of ractopamine and metabolizable energy, Evans et al. (2009) found that ractopamine inclusion decreased SFA and increased MUFA content of subcutaneous fat and intramuscular fat depots; however, ractopamine supplementation did not change fatty acid profiles of belly fat. Inclusion of ractopamine in the diet increased dressing percentage, decreased backfat depth, tended to decrease the SFA

content in bellies, but no other fatty acid properties were changed (Weber et al., 2006). Similarly, Apple et al. (2007) and Leick et al. (2010) concluded that the addition of ractopamine did not change belly firmness or significantly alter the fatty acid profile of pork fat depots. However, Weber et al. (2006) concluded that CLA, added soybean oil, and ractopamine work in an additive fashion to enhance carcass quality.

## **Tallow as a Supplemental Fat Source**

### *Digestibility*

Numerous studies have determined the fatty acid digestibility of tallow in swine diets. In general, vegetable fats are better digested compared to fats of animal origin (Cera et al., 1988; Cera et al., 1989). It is well documented that fecal digestibility values are greater compared to ileal digestibility values when tallow is included in the diet (Ozimek et al., 1984; Duran-Montge et al., 2007). The increase in fecal digestibility coefficients may be due to the contribution of lipid from microorganisms in the hindgut (Cho and Salton, 1966; Dowhan, 1997). However, ileal digestibility values serve as a better reference point because absorption of fatty acids primarily occurs in the small intestine. Saturated fatty acids tend to have a lower ileal digestibility than unsaturated fatty acids (Jorgensen et al., 1993; Overland et al., 1994). Table 1.5 is a compilation of four studies that determined ileal digestibility of selected fatty acids from either basal diets or diets that contained various types of animal fat (rendered fat or tallow). In one study, the digestibility coefficients were negative implying that there was too little C18:1 in the diet, thus providing incorrect estimations of digestibility of C18:1.

Table 1.5 Ileal digestibility of select fatty acids in control diets and diets containing animal fat

<u>Basal diets only</u>				
	n	Minimum	Average	Maximum
C16:0	4	74.6	83.7	90.9
C16:1	2	69.6	79.1	88.5
C18:0	4	-220.7	-24.3	76.4
C18:1	4	73.9	89.0	92.1
C18:2	4	75.4	88.5	98.5
C18:3	3	82.3	86.7	92.3
<u>Animal fat diets</u>				
C16:0	10	64.3	82.4	94.5
C16:1	9	69.6	88.2	98.7
C18:0	10	-157.6	47.3	93.0
C18:1	10	85.1	93.7	97.5
C18:2	10	87.2	95.4	99.0

Adapted from Ozimek et al., 1984; Overland et al., 1994; Jorgensen et al., 1993; Duran-Montge et al., 2007.

### *Growth Performance*

Increasing dietary corn oil levels improves average daily gain, reduces daily feed consumption, and improves gain:feed (Allee et al., 1971; Azain et al., 1991; Smith et al., 1999; Engle et al., 2001). However, Seerley et al. (1978) did not detect any differences in growth performance when feeding animal or poultry fat compared to feeding a corn-soybean meal control diet. Allee et al. (1971) found that the addition of tallow to the diet resulted in a tendency for pigs to gain faster and more efficiently. Barrows also gain faster and tend to have a lower gain:feed ratio compared to gilts when fed diets containing various levels of corn oil (Allee et al., 1971).

### *Carcass Characteristics*

Miller et al. (1990) observed an increase in last-rib carcass fatness with addition of 10% animal fat but did not specify the exact source. Loin muscle area was not affected with addition of animal fat to the diet (Miller et al., 1990). Furthermore, belly thickness was not affected with the addition of 5% beef tallow to the diet (Apple et al., 2007). Gilt carcasses contained less backfat, a greater percentage of lean cuts, and a greater *l. dorsi* muscle area than barrow carcasses when dietary fat (from corn oil) increased in the diet (Allee et al., 1971).

### *Fat Quality*

Pigs fed diets containing highly unsaturated sources of fat, such as safflower oil, sunflower oil, canola oil, have less firm carcass fat which appears oily due to the lower melting point of the unsaturated fatty acids (Miller et al., 1990). Carcass fat appeared more oily and softer for pigs fed safflower oil compared to when animal fat or control diets were fed (Miller et al., 1990). Inconsistent responses have been reported with the addition of tallow to swine diets. Apple et al. (2007) observed increased total saturated fatty acid levels of belly fat with dietary tallow inclusion compared to soybean oil inclusion. However, palmitic and stearic acids, the two predominate saturated fatty acids in tallow, did not differ in backfat of pigs fed 10 or 20% tallow compared with control pigs (Brooks, 1971). Monounsaturated fatty acids increased linearly as dietary tallow inclusion increased from 2.5 to 5.0% in a corn-soybean based diet (Averette Gatlin et al., 2002). Furthermore, including 10 or 20% tallow resulted in a dramatic reduction of linoleic acid in backfat (Brooks, 1971; Averette Gatlin et al., 2002) and a reduction in IV (Apple et al., 2007). Likewise, including tallow in the diet resulted in the reduction of the unsaturated/saturated ratio in backfat (Brooks, 1971; Apple et al., 2007). Belly-

suspension measurements, as indicators of fat firmness, from pigs fed beef tallow were firmer than from pigs fed soybean oil, and belly fat color scores remained unaffected with the addition of 5% tallow (Apple et al., 2007).

#### *Pork Quality and Tallow*

Lean color, firmness, and texture scores of pork were not different for diets supplemented with either 10% animal fat or 10% safflower oil compared to control diets (Miller et al., 1990). Sensory traits between loin chops from animals fed control diets and diets containing 10% animal fat did not differ (Miller et al., 1990). Additionally, thaw loss, cooking loss, and total weight loss did not differ with addition of fat (Miller et al., 1990). Leszczynski et al. (1992) found no significant difference with 4% tallow addition between saturated and unsaturated fatty acids in longissimus muscle. However, bellies exhibited a greater change in fatty acid profile compared to the longissimus muscle. Tallow addition caused the fatty acid composition of bacon to be less saturated and more unsaturated (Leszczynski et al., 1992). Addition of 5% tallow did not affect objective color scores of L\*, a\*, or b\* for the rectus abdominus muscle (Apple et al., 2007).

### **DDGS and Tallow Interactions**

#### *Growth Performance and Carcass Characteristics*

Little research has been published on the interactions of combining a saturated fat source and fibrous feedstuff such as DDGS in diets for growing-finishing pigs on growth performance and carcass characteristics. Feoli et al. (2007a,b; 2008) fed a combination of a saturated fat source (tallow) and sorghum-based DDGS to growing-finishing pigs. In

2007, they measured growth performance and carcass characteristics of finishing pigs fed diets containing beef tallow and 40% sorghum-based DDGS. The experimental diets consisted of a corn-soybean meal control diet and three diets containing 40% DDGS with 0, 2.5, or 5% added tallow to assess the effects of using a saturated fat source with sorghum DDGS. Average daily gain and ADFI were higher for pigs fed the control diets compared to pigs fed DDGS. However, increasing tallow from 0 to 5% in the diet resulted in a linear increase in hot carcass weight, dressing percentage, and linear decrease in backfat thickness. However, supplemental tallow additions did not improve fat quality as measured by the iodine value of jowl fat. These results suggest that a saturated fat source such as tallow will not counteract the negative effects of 40% sorghum DDGS for finishing pigs even though a few carcass characteristics are improved.

Later, in 2008, Feoli and co-workers reported the effects of adding various saturated fat sources including beef tallow, palm oil, stearic acid, and coconut oil to diets containing 40% sorghum-based DDGS on growth performance and carcass characteristics. Their results demonstrated that using 40% sorghum DDGS with 5% added fat, tended to reduce ADG, improve F:G, and reduce carcass fat firmness for all fat sources except coconut oil. When 5% coconut oil was added to the DDGS diets, the researchers found that carcass fat firmness levels, measured by iodine value of the jowl fat, subjective scoring of belly firmness, and tip-to-tip distance of the bellies, was as good as, or better than the carcass firmness characteristics of the corn-soybean meal control treatment. Results from Feoli et al. (2008) suggest that carcass firmness may be improved with the addition of coconut oil. The experiments (Feoli 2007a,b; 2008) imply

that feeding 5% tallow and 40% DDGS does not improve pork carcass fat quality measurements.

### *Fat and Fiber Digestibility*

Apparent ileal digestibility and apparent total tract digestibility of fat increases as the amount of dietary fat increases (Jorgensen and Fernandez, 2000; Stein, 2009; Kil et al., 2010). However, the average apparent digestibility of extracted fat from corn oil was greater than that of intact fat from corn germ meal, 81.9 and 63.2%, respectively (Kil et al., 2010). Intact fat sources, such as corn germ meal or DDGS, may have lower digestibility values because digestive enzymes may not have access to the substrate lipid because carbohydrate molecules, specifically fiber, may block access to the digestive lipase. Furthermore, the addition of increasing amounts of purified neutral detergent fiber (NDF) did not change apparent ileal digestibility (AID), true ileal digestibility (TID), or true total tract digestibility (TTTD) of fat (Kil et al., 2010). Conversely, other results have demonstrated that increasing NDF content of the diet decreases the apparent digestibility of fat (Just, 1982; Hansen et al., 2006).

### **Digestibility Procedures**

Many different methodologies exist to determine fatty acid digestibility in pigs. Most fatty acid digestibility studies utilize a T-cannula located at the terminal ileum (Ozimek et al, 1984; Jorgensen et al., 1993; Htoo et al, 2008). With this technique, the normal physiological function of the digestive tract remains intact. Although simple T-cannulation is one of the most common techniques utilized to collect digesta, it does not

allow for total collection of digesta. Digestibility must be calculated based on an indigestible marker.

Other techniques used to determine fatty acid digestibility in pigs include: post-valvular T-cecum (PVTC) (Overland et al., 1994, Yen et al., 2001b) and ileo-rectal anastomosis (IRA) (Duran-Montge et al., 2007). The cecum is completely removed in the PVTC cannulation method and is replaced by a large, silicone T-cannula. Drawbacks associated with the PVTC method relate to the possible physiological effect of cecectomy on intestinal physiology (Yen 2001b). Finally, an alternative to ileal cannulation, is the ileo-rectal anastomosis (IRA). This procedure surgically attaches the ileum to the rectum which allows digesta to bypass the large intestine and be excreted via the anus for total collection (Gabert et al., 2001; Yen, 2001b). The IRA method has been used for determination of fatty acid digestibility, but it is largely criticized from an animal welfare perspective because pigs discharge digesta from the anus following surgery and have a greater demand for electrolytes and water. Other techniques used to determine digestibility include the slaughter method; steered ileo-cecal-valve (SIVC) where the cecum is not removed; and reentrant cannulation, where the flow of digesta is diverted outside of the pig and returned to either the ileum or cecum.

Length of diet adaptation periods for nutrient digestibility research trials are inconsistent as reported in the scientific literature. Adaptation periods can be as few as 2 days (Cera et al., 1988; Cera et al., 1989) to as many as 12 days (Noblet and Shi, 1993). However, a 5-day adaptation period has been most frequently used (Jorgensen et al., 1993; Jorgensen et al., 2000; Duran-Montge et al., 2007; Mitchaothai et al., 2008).

Inert marker selection and use also varies among published swine nutrient

digestibility studies. Common markers include chromium oxide, titanium dioxide, and acid-insoluble ash. Markers are used to account for changes in the concentration of a given nutrient (Gabert et al., 2001). As the nutrient of interest is digested and absorbed, the concentration of the marker increases. When selecting an indigestible marker, it must not be absorbed from the digestive tract, must be inert, and must not alter digestive events. Chromium oxide has been is the most widely used marker for digestibility studies. However, several researchers have reported problems with recovery of the marker (Moore, 1957, McCarthy et al, 1974, Yin et al., 2001). Furthermore, chromium oxide may have a carcinogenic effect. Although used less frequently, titanium dioxide is another marker option. Titanium dioxide has higher recovery rates and is less variable compared to chromium oxide (Jagger et al., 1992; Kavanagh et al. 2001). According to Kerr et al. (2010), titanium dioxide is the preferred marker compared to chromic oxide or iron oxide because it does not alter microbial numbers or bacteria diversity. Yet, when chromic oxide, iron oxide, and titanium dioxide were compared, no difference in nutrient digestibility was found (Kerr et al., 2010). Finally, acid-insoluble ash (AIA) is a naturally occurring marker in the diet, but can increase the AIA content with the addition of Celite (Kavanagh et al., 2001). Kavanagh et al. (2001) reported that fecal marker recovery was greatest for AIA, lowest for titanium dioxide, and intermediate for chromic oxide, 99.9, 92.3, and 96.0%, respectively.

For future digestibility studies, the choosing the best method is contingent upon a variety of variables. First, the specific procedure selected must meet the needs, resources, and capabilities of the researcher. Next, factors such as the number of animals and housing availability should be considered to determine the length and number of

adaptation and collection periods. Finally, selection of inert markers is also an important factor to consider because availability of the marker and recovery during laboratory analysis are critical for accurate determination of nutrient digestibility.

## **Summary**

Overall, it is clear that pork fat quality is reduced when high concentrations of DDGS are fed to swine during the growing and finishing phases. Although certain feeding strategies and management practices exist to minimize the negative consequences associated with feeding high levels of DDGS, these alternatives are not always readily available or economical to be implemented by pork producers. Beef tallow is a readily available and relatively inexpensive supplemental fat source. Due to its low IV and high level of saturated fatty acids, it appears to be an ideal choice as a supplemental dietary saturated fat source compared to other animal fats or conventional vegetable oils. The addition of tallow to the diet may offset the negative effects on pork fat quality when feeding diets containing high levels of unsaturated fatty acids from DDGS. Furthermore, the addition of tallow to swine diets has been shown to increase the saturated fatty acids in the pork depot fat. By feeding these two feedstuffs, pork fat quality issues may be alleviated even though previous research results reported by Feoli et al. (2007a,b; 2008) have indicated the contrary when feeding sorghum DDGS diets. However, the effect of feeding corn DDGS on fatty acid digestibility and how digestibility relates to pork fat depot fatty acid profiles remains unclear. The objectives of the following studies are to assess the effects of adding supplemental tallow to diets containing 30% DDGS on growth performance, carcass characteristics, pork fat quality, and fatty acid digestibility.

## **CHAPTER 2**

**Effects of adding supplemental tallow to diets containing 30% DDGS on growth performance, carcass characteristics, and fat quality in growing-finishing pigs**

## **OVERVIEW:**

A study was conducted to determine the effect of supplementing 5% beef tallow to grower-finisher diets containing 30% corn dried distillers grains with solubles (DDGS) on pig growth performance, carcass characteristics, and pork fat quality. Crossbred pigs (n = 315) were blocked by initial BW ( $6.8 \pm 1.1$  kg) and randomly assigned to 1 of 4 dietary treatments in a 3-phase feeding program using a  $2 \times 2$  factorial arrangement of treatments. Pigs were housed in a confinement facility containing 40 pens, with 7 to 8 pigs per pen, to provide 10 replications per treatment. Gilts and barrows were housed separately but fed common diets formulated to contain similar levels of available P and Standardized Ileal Digestible Lys:ME among treatments. Diets consisted of the following: corn-soybean meal control diet (CON), corn-soybean meal diets containing 5% tallow (T), 30% DDGS (D), and the combination of 5% tallow and 30% DDGS (TD). Individual pig BW and pen feed disappearance were obtained to calculate ADG, ADFI, and G:F approximately every 2 wk. For fat quality characteristics, one pig from each pen was selected that was the closest to average pen BW at the time of harvest (n = 20 barrows and 20 gilts). Data were analyzed using the Proc Mixed functions of SAS with random effect of block and fixed effects of DDGS, tallow, gender, and DDGS  $\times$  tallow. Barrows had higher ADG, ADFI, and backfat, but lower G:F, and percentage carcass lean than gilts ( $P < 0.01$ ). Overall ADG did not differ among treatments, but ADFI was higher for pigs fed CON and D (2.8 and 2.8 kg/d, respectively) due to lower diet caloric density compared with T and TD (2.6 and 2.5 kg, respectively;  $P < 0.01$ ). Consequently, pigs fed T and TD had higher G:F (0.40 and 0.41, respectively;  $P < 0.01$ ) than those fed CON and D (0.37 and 0.37, respectively). Carcass yield was greater for pigs fed T and TD (79.5

and 79.4%, respectively) compared with pigs fed CON and D (78.8 and 78.3%, respectively;  $P < 0.01$ ). Backfat depth was reduced for pigs fed DDGS diets ( $P < 0.02$ ), but increased for pigs fed tallow diets ( $P < 0.01$ ), compared with CON. Hunter L\* and b\* values for backfat and belly fat were greater ( $P < 0.01$ ) for pigs fed CON and T diets compared to pigs fed D and TD diets. Similarly, Japanese Color Score for belly fat was higher ( $P < 0.03$ ) for pigs fed D and TD. Pigs fed D and TD exhibited softer bellies compared to pigs fed CON and T as indicated by a lower belly flop angle ( $P < 0.01$ ). An interaction between DDGS and tallow ( $P < 0.03$ ) was observed for belly fat iodine value (IV), indicating that tallow reduced IV when DDGS was included in the diet, compared to IV of pigs fed diets containing DDGS without tallow. Saturated fatty acid (SFA) levels in belly fat were reduced ( $P < 0.01$ ) for T, D, and TD compared to CON. Belly fat MUFA was not different for pigs fed diets containing DDGS (D and TD), but greater ( $P < 0.01$ ) for pigs fed tallow containing diets (T and DT). Belly and backfat PUFA were higher ( $P < 0.01$ ) for pigs fed D and TD compared to CON and T. Backfat IV increased ( $P < 0.01$ ) when either DDGS or tallow were included in the diet compared to CON. In summary, adding 5% tallow to 30% DDGS diets improved G:F and carcass yield, but pigs fed TD tended to have increased backfat depth compared to pigs fed CON. Adding 5% tallow to diets containing 30% DDGS did not improve pork fat firmness.

**Key words:** DDGS, pigs, pork fat quality, beef tallow

## INTRODUCTION

Corn dried distillers grains with solubles (DDGS) is a readily available and economical co-product of ethanol production, and is commonly added to grower-finisher swine diets to partially replace corn, soybean meal, and inorganic phosphorus. However, typical DDGS sources contain 10% oil, of which nearly 60% consists of the polyunsaturated fatty acid, linoleic acid (C18:2; Xu et al., 2010b). Although some negative growth performance responses have been reported (Whitney et al., 2006; Linneen et al., 2008), results from several studies have shown that growth performance of growing-finishing pigs is often unaffected compared to feeding corn-soybean meal diets when levels up to 30% DDGS are added (Cook et al., 2005; DeDecker et al., 2005; Gaines et al., 2007). Changes in carcass dressing percent are inconsistent when adding DDGS to grower-finisher diets (Stein and Shurson, 2009), but pork fat quality is consistently reduced. Specifically, when pigs are fed increasing levels of DDGS, polyunsaturated fatty acids (PUFA), C18:2 content, and iodine value (IV) of pork fat are increased (Widmer et al., 2008 ; Xu et al., 2010b), resulting in reduced belly firmness. Because tallow is an economical and readily available saturated fat source for use in animal feed, adding it to diets containing high levels of DDGS may override the negative consequences associated with feeding DDGS on pork fat quality. Currently, little information exists on the effects of feeding DDGS diets with supplemental tallow on growth performance, carcass characteristics, and pork fat quality of grower-finisher pigs. The objective of this study was to assess the effects of feeding 0 or 30% DDGS, with and without supplemental tallow (0 or 5 %), on growth performance, carcass characteristics, and pork fat quality of growing-finishing pigs.

## **MATERIALS AND METHODS**

### ***Animals***

The University of Minnesota Institutional Animal Care and Use Committee approved all experimental procedures. A total of 315 mixed sex pigs were housed in an environmentally controlled grower-finisher facility at the University of Minnesota Southern Research and Outreach Center in Waseca, MN. Pigs were blocked by initial BW ( $6.8 \pm 1.1$  kg). Barrows and gilts were housed in separate pens (2.0 m  $\times$  3.0 m; 7 to 8 pigs/pen). Pens (n = 40) consisted of totally slatted concrete flooring, a self-feeder with two spaces, and one cup drinker. When the average BW of pigs in each pen was about 30 kg, pens were randomly assigned to 1 of 4 dietary treatments for the beginning of the experiment.

### ***Dietary Treatments***

A single lot of DDGS was obtained from Absolute Energy LLC (Lyle, MN) and one batch of tallow was sourced from Origo (New Ulm, MN). Samples of DDGS were analyzed for mycotoxins (HPLC) and fatty acid profile (AOCS 996.06), while tallow was analyzed for moisture (AOCS Ca2C-25), impurities (Ca3A-46), and unsaponfiabiles (Ca6A-40; MIU) and fatty acid profile (AOCS 996.06) by Minnesota Valley Testing Laboratories (New Ulm, MN; Table 2.1 and Table 2.2) before diet formulation. Proximate analysis (moisture, AOAC Official Method 934.01; crude fat, AOAC Official Method 9290.39; crude fiber, AOAC Official Method 978.10, 2006; ash, AOAC Official Method 942.05; crude protein, AOAC Official Method 984.13) and amino acid (AOAC Official Method 982.30) content of DDGS were analyzed by the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO). Mycotoxin

levels for aflatoxin, fumonisin, vomitoxin, and zearalenone were below industry thresholds (200 ppb, 5ppm, 1ppm, 3 ppm, respectively; NSNG, 2010). Similarly, MIU concentration of tallow was 0.42% indicating good quality. Diets consisted of the following: corn-soybean meal control (CON), CON diet plus 5% tallow added at the expense of corn (T), CON plus 30% DDGS (D), and CON plus 5% tallow and 30% DDGS (TD; Table 2.3, Table 2.4). All diets were formulated to contain similar standardized ileal digestible (SID) Lys:ME and available P content. All other nutrient requirements met or exceeded NRC (1998) recommendations for pigs based on a lean tissue gain of 350 g/d. Dietary levels of ME and SID Lys varied among dietary treatments within each phase, but the SID Lys:ME ratio was maintained constant.

#### ***Growth Performance Measurements***

Pigs were monitored on a daily basis to observe any adverse health conditions. Individual pig weights and pen feed disappearance were measured at 2 wk intervals to determine ADG, ADFI, and G:F. Pigs were fed according to a 3-phase feeding program with diets changing by phase when average pen BW of 60 or 90 kg was reached. Pigs had *ad libitum* access to feed and water for the duration of the experiment.

#### ***Carcass Measurements***

The day prior to harvest, pigs (n = 315) were tattooed and weighed individually for subsequent carcass identification. Pigs were harvested when the average BW of all pigs was 113 kg. Carcass measurements were obtained at a commercial abattoir. Hot carcass weight was determined on-line. All carcass characteristic measurements were obtained from the right side of the carcass. Last rib backfat thickness and loin depth were measured using ultrasound by a trained and certified technician at the abattoir. These

data, along with hot carcass weight (HCW) were determined at the commercial abattoir, were used to calculate the percentage of carcass fat free lean according to procedures described by NPPC (2002).

### ***Pork Fat Analysis***

For pork fat quality measurements, one pig per pen (n = 20 gilts and 20 barrows) was selected based on BW closest to the average pen BW. Belly length and thickness were measured and recorded as described by Scramlin et al. (2008). The degree of belly firmness was assessed by draping the belly skin side down over a smoke stick. Distance between the inner edges was recorded. The degree of firmness was calculated based on the following equation (Xu et al, 2010):  $\text{Degree} = (\cos^{-1}[(0.5(L^2)-D^2)/(0.5(L^2))])$ , where L is half the belly length and where D is the distance between the two ends. Prior to measurement, bellies were squared up and measured approximately 57.6 cm in length but belly width was not recorded.

Fat samples were collected from the belly and backfat for fatty acid analysis and IV calculation. Belly tissue samples, approximately 5-cm diameter were collected at the midline opposite the last rib. Similarly, a 5-cm sample of back fat was collected at the 10th rib on the right side of each carcass. Belly and backfat were measured for lightness (L\*), redness (a\*), and yellowness (b\*) using a HunterLab Miniscan with a D65 illuminant at 10° (Hunter Associates Laboratory, Inc., Reston, VA). Belly and backfat samples were also evaluated for visual fat color by 8 panelists using the NPPC (2000) Japanese fat color scale (1 = white to 4= yellow). Once fat color scores were obtained, samples were packed in sealed sample bags, and frozen at -18° C until fatty acid analysis was performed.

Upon analysis, fat was extracted using the Folch et al. (1957) method where a 2:1 chloroform:methanol mixture was used. Extracted fat was methylated to produce fatty acid methyl esters for gas chromatography according to modifications based on the work of Metcalfe and Schmitz (1961). Fatty acid profile was determined utilizing gas chromatography according to AACC 58-17. Iodine value was calculated utilizing the following equation (AOCS, 1998):  $(C16:1 \times 0.95) + (C18:1 \times 0.86) + (C18:2 \times 1.732) + (C18:3 \times 2.616) + (C20:1 \times 0.785) + (C22:1 \times 0.723)$ .

### ***Statistical Analysis***

Each pen was used as the experimental unit for all data analysis. All analyses were conducted utilizing the Mixed Procedure of SAS (SAS Inst. Inc., Cary, NC). Dietary treatments were arranged in a 2 × 2 factorial with random effect of block and fixed effects of gender, DDGS, tallow, and DDGS × tallow. The significance level was declared at  $P < 0.05$  and trends are described at  $0.10 > P > 0.05$ . The pdiff option with Tukey adjustment was used for comparison of treatment least squares means. Pearson correlation coefficients were determined for associations between the belly and backfat IV to the IV of the diet using the CORR procedure of SAS (SAS Inst. Inc., Cary, NC).

## **RESULTS AND DISCUSSION**

### ***Growth Performance***

No pigs died during the experiment. Overall, ADG did not differ ( $P > 0.05$ ) among dietary treatments (Table 2.5). There tended ( $P < 0.06$ ) to be an interaction between DDGS and tallow for overall ADFI where the addition of tallow, regardless of DDGS inclusion, depressed overall ADFI. A main effect of tallow existed for pigs fed T

and TD indicating lower ( $P < 0.01$ ) overall ADFI compared with pigs fed CON and D for all phases. Similarly, pigs fed D and TD ( $P < 0.04$ ) exhibited lower overall ADFI compared to pigs fed CON and T diets. Consequently, overall G:F was improved ( $P < 0.01$ ) for pigs fed tallow (T and TD) compared to pigs not fed the tallow diets (CON and D).

In a review by Stein and Shurson (2009), growth performance was usually not affected by inclusion of up to 30% DDGS in growing-finishing diets. Specifically, 18 of 25 experiments showed no change in ADG, 15 of 23 experiments had no change in ADFI, and 16 of 25 experiments showed no change in G:F. Occasionally, dietary DDGS inclusion improved growth performance responses with 1 of 25, 2 of 23, and 4 of 25 experiments for ADG, ADFI, and G:F, respectively. However, in 6 of 25, 6 of 23, and 5 of 25 experiments had reduced ADG, ADFI, and G:F, respectively. Although in the present experiment, ADG remained unchanged with the inclusion of DDGS compared to CON, other performance criteria were negatively impacted by including 30% DDGS in the diet. Specifically, ADFI was reduced with the addition of DDGS. This measure may have been reduced due to reduced palatability of the DDGS source used as observed by Hastad et al. (2005a). For example, DDGS may be considered poor quality if it has been subjected to excessive drying temperatures causing a reduction in digestible amino acid content (Stein and Shurson, 2009).

Increasing dietary fat level improves ADG, reduces ADFI, and improves G:F (Allee et al., 1971; Srichana et al., 2005; Hastad et al., 2005b). Reductions of ADFI are primarily caused by the increase in caloric density of the diet (Averette Gatlin et al., 2002). Srichana et al. (2005) reported a 0.78 and 0.80% improvement in ADG for early

and late finishing pigs, respectively, for every one percentage of supplemental fat added to the diet. Likewise, for every one percentage addition of supplemental dietary fat, G:F improves 1.30 and 1.29% for early and late finishing pigs, respectively (Srichana et al., 2005). Allee et al. (1971) found that the addition of tallow at 4, 7, and 10% of diets tended to cause pigs to gain faster and more efficiently compared to pigs fed a 1% tallow-containing diet. Likewise, Linneen et al. (2008) reported that ADG and G:F improved linearly as the level of choice white grease increased from 0 to 3 or 6%. However, when feeding a diet containing 30% DDGS and 3% choice white grease, DeDecker et al. (2005) found no difference in ADG compared to the control, but observed a reduction in ADFI and an increase in G:F. Similarly, when feeding a diet containing 45% DDGS and 0 or 5% tallow formulated on a true ileal digestible (TID) AA basis, keeping TID lys:ME constant, Ulery et al. (2010) reported that adding tallow improved ADG and G:F. When 40% sorghum DDGS and 5% beef tallow were fed to pigs, no difference was observed in G:F, however, ADG and ADFI were lower compared to the corn-soybean meal control diet (Feoli et al., 2007a; Feoli et al., 2008). In the present study, an interaction between DDGS and tallow tended to occur ( $P < 0.06$ ) for ADFI. In this case, ADFI was reduced when tallow was added to the diet irrespective of the content of DDGS. However, results from a similar experiment using choice white grease showed no interaction (DeDecker et al., 2005). Overall, responses due to the addition of supplemental tallow are relatively consistent in improving ADG, reducing ADFI, and consequently improving G:F.

Growth performance responses for genders observed in the current study are in agreement with previous findings (Chen et al., 1999; Latorre et al, 2004, Xu, 2010b) where barrows had a higher ADG and ADFI compared to gilts. These results are not

surprising since lean tissue and fat deposition differ between barrows and gilts. Barrows typically consume more feed, and thus energy, than gilts, and because barrows have a lower energy need for lean tissue synthesis, extra energy is stored as fat (Cline and Richert, 2001).

### *Carcass Characteristics*

No pigs were removed from the experiment and all were harvested. Least squares means for carcass characteristic responses are presented in Table 2.6. Pigs fed T had greater ( $P < 0.02$ ) HCW compared with pigs fed CON and D, but were not different from TD. The addition of DDGS tended ( $P < 0.08$ ) to cause a reduction of HCW compared to pigs not fed DDGS. When more than 20% DDGS is fed to growing finishing pigs, HCW may be reduced (Fu et al, 2004; Whitney et al., 2006; Linneen et al., 2008), whereas results from other studies showed no change in HCW due to the addition of DDGS to the diet (Benz et al., 2007; Xu et al., 2010b). The different responses in HCW may actually be attributed to differences in visceral organ weight and gut fill. Previous research has demonstrated that pigs fed high levels of fiber have increased gut fill and greater visceral organ weight (Moeser et al., 2002). Pigs fed diets containing DDGS consumed more crude fiber and NDF compared to pigs not fed DDGS containing diets (Table 2.4) due to the fact that DDGS contains a higher concentration of fiber compared to corn and soybean meal.

Percentage carcass yield and loin depth did not differ due to the addition of 30% DDGS, and there was no DDGS  $\times$  tallow interaction, which agrees with results reported by Fu et al. (2004) and Widmer et al. (2008). However, Feoli et al. (2008) observed that adding 5% fat to sorghum DDGS diets tended to improve dressing percentage.

Conversely, Cook et al. (2005) and Gaines et al. (2007) reported a reduction in carcass yield when feeding diets containing up to 30% DDGS. However, Gaines et al. (2007) also detected a reduction in loin depth with feeding DDGS. Carcass yield is often an inconsistent response when feeding DDGS. These inconsistencies may be due to increased gut fill and increased intestinal mass due to feeding fiber rich ingredients (Kass et al., 1980; Anugwa et al 1989; Hansen et al., 1992). However, in the present study, the addition of tallow caused a significant increase in carcass yield ( $P < 0.01$ ) where pigs fed T and TD had higher yields compared with pigs fed CON and D. These results are consistent with those of other investigators who have demonstrated that adding supplemental fat increases carcass yield (Hale, et al., 1968; Jackson et al., 2009).

Feeding 30% DDGS caused a reduction in last-rib backfat depth ( $P < 0.02$ ) compared to excluding DDGS from the diet. Similarly, including tallow in the diet caused an increase ( $P < 0.01$ ) in backfat depth compared to not feeding tallow. The results of the present study disagree with previous reported results (Cook et al., 2005; Whitney et al., 2006; and Widmer et al., 2008), which did not show any differences in backfat depth as a result of feeding DDGS diets. However, Xu et al. (2010b) found a similar response of backfat reduction while feeding DDGS with backfat depths at 2.92 and 2.74 cm for the control diet and 30% DDGS diet, respectively. Our results agree with those from Xu et al. (2010b), where pigs fed DDGS had lower backfat depths compared to pigs fed the control diet. Furthermore, the reduction in backfat observed in the current study may be explained by the reduction in ADFI with feeding DDGS. Since addition of 30% DDGS caused a reduction in feed intake, energy intake was reduced, and, hence, less energy was available for backfat deposition. However, a reduction in

ADFI does not necessarily cause a reduction in backfat depth (Fu et al., 2004). Adding supplemental tallow to the diet caused an increase in backfat depth ( $P < 0.01$ ), with pigs fed T exhibiting greater backfat depth compared to all other treatments. These results are in agreement with those previously reported (Miller et al., 1990; Averette Gatlin et al., 2002).

Percentage carcass fat free lean was not affected by dietary DDGS inclusion, which agrees with previous research results (Fu et al., 2004; Cook et al., 2005; Whitney et al., 2006), but not those reported by Gaines et al. (2007). However, carcass lean percentage was reduced ( $P < 0.01$ ) when 5% tallow was included in the diet compared to diets not containing tallow. Conversely, Averette Gatlin et al. (2002) did not detect any differences in carcass lean as a result of feeding various types of supplemental fat. The reduction in percent carcass lean may be attributed to the increased energy density of the tallow containing diets. Diets containing 5% tallow had higher calculated ME values and, therefore, a greater concentration of energy to compensate for the reduction in ADFI from pigs fed tallow. Excess energy above the pig's requirement may have been partitioned toward adipose tissue deposition. A significant interaction between DDGS and tallow for percentage carcass lean was detected ( $P < 0.04$ ). This interaction can be explained by pigs fed the TD exhibiting an intermediate carcass lean percentage between T and D, yet a lower carcass lean compared to pigs fed CON.

#### *Fatty Acid Composition and IV of Backfat and Belly Fat*

Pork fat quality can be characterized by belly firmness, iodine value (IV), and fatty acid composition. Belly firmness, as measured by the belly flop angle, is a more subjective measurement, but it is a visual tool to define fat firmness. Iodine value can be

calculated from the fatty acid profile of adipose tissue and provides a value relative to the degree of unsaturation in pork fat. Finally, the fatty acid profile of pork fat is the most specific indicator of pork fat quality. Pork fat quality is of particular importance to bacon and sausage processors (NPPC, 2000) because soft fat, or fat high in unsaturated fatty acids, creates challenges associated with processing. Specifically, in bacon production, soft fat produces bacon slices that appear oily, flatten together, separate from lean, and are subject to faster rates of oxidation. Current industry standards define quality pork fat as having less than 15% polyunsaturated fatty acids, more than 15% stearic acid, and an IV of less than 70 (NPPC, 2000). Previous work has correlated high C18:2 content with poor fat quality (Cameron and Esner, 1991). Furthermore, Rentfrow et al. (2003) reported that soft pork fat is associated with more than 14% linoleic acid.

Using average belly thickness as a covariate, belly firmness, measured by the belly flop angle, was reduced for pigs fed D or TD ( $P < 0.01$ ) compared to pigs fed CON or T (Table 2.7). The reduction in belly firmness is in agreement with previous research when 30% DDGS is included in the diet (Whitney, et al., 2006, Widmer et al., 2008; Xu et al., 2010b). The addition of tallow tended to improve belly firmness compared to diets not containing tallow. However, when Feoli et al. (2008) fed diets containing sorghum-DDGS and 5% stearic acid or coconut oil, they found that the addition of these fat sources improved the subjective scoring of belly firmness and tip to tip distance between belly ends, which indicates the synergistic effects of feeding diets containing DDGS and tallow. Stearic acid is the main saturated fatty acid found in tallow, and may be related to improvements in belly firmness with dietary inclusion of tallow.

Bellies tended ( $P < 0.07$ ) to be thicker for pigs fed diets containing tallow

compared to pigs not fed tallow, but no main effect of DDGS was evident for belly thickness (Table 2.7). From the literature, belly thickness responses from feeding DDGS diets are inconsistent. Whitney et al. (2006) found pigs fed 20 or 30% DDGS had thinner bellies compared to pigs fed 0 or 10% DDGS, whereas Widmer et al. (2008) did not report any difference in belly thickness as a result of feeding DDGS. Contrary to the results from the present study, belly thickness was not affected due to addition of 5% beef tallow to grower-finisher diets (Apple et al., 2007). Despite the results from the present study and those reported in the literature, belly thickness may be a function of slaughter weight, even though final body weight was not different, because heavier animals at harvest have thicker bellies due to increased fat deposition (Correa et al., 2008).

No DDGS × tallow interactions were detected for pork fatty acid profile in belly or backfat (Table 2.8). However, main effects of DDGS and tallow were observed in belly fat and backfat. The lack of interactions suggests that DDGS and tallow do not synergistically affect pork fat depots. The addition of DDGS or tallow to the diet reduced total SFA in both belly and backfat depots ( $P < 0.01$ ). Palmitic acid (C16:0) tended ( $P < 0.07$ ) to be lower for pigs fed diets containing DDGS in the backfat, but belly fat C16:0 content was not affected by addition of 30% DDGS to the diet. In backfat, C16:0 was reduced with the addition of tallow ( $P < 0.01$ ). Stearic acid (C18:0) was lower ( $P < 0.02$ ) in belly fat, but not different in backfat, for pigs fed D and TD compared to pigs fed CON and TD. The reduction of these two saturated fatty acids caused by an increase in DDGS level agrees with previous results (Benz et al., 2007; White et al., 2009; and Xu et al., 2010b). Pigs fed T and TD had lower C16:0 content in belly and backfat, and C18:0 was reduced for pigs fed T and D in belly fat ( $P < 0.01$ ).

In backfat, the addition of 30% DDGS decreased MUFA content ( $P < 0.01$ ) compared to diets not containing DDGS while the dietary inclusion of 5% tallow compared to diets not containing tallow increased MUFA in both backfat and belly fat depots (Table 2.8). Pigs fed D and TD compared with CON and T had lower levels ( $P < 0.04$ ) of palmitoleic acid (C16:1) in belly fat, but no differences for C16:1 were observed among treatments for backfat. Dietary tallow inclusion did not influence C16:1, but oleic acid (C18:1) increased in both belly and backfat when pigs were fed T and TD ( $P < 0.001$ ) compared with CON and D. Similarly, pigs fed D and TD had lower concentrations of C18:1 in the backfat ( $P < 0.01$ ), and C18:1 tended to be lower in belly fat ( $P < 0.08$ ) compared with pigs fed non-DDGS diets. Xu et al. (2010b) found similar results while feeding diets containing up to 30% DDGS. Similar to the results from the current study, MUFA concentrations increased in backfat when dietary tallow concentration increased from 0 to 5% compared to other dietary fat sources (Averette Gatlin et al., 2002).

Addition of 30% DDGS to the diets nearly doubled the PUFA concentration in both backfat and belly fat ( $P < 0.01$ ) compared with CON and T. Linoleic acid (C18:2) concentrations were higher ( $P < 0.01$ ) in both belly and backfat when pigs consumed diets containing DDGS compared to diets not containing DDGS. These findings are in agreement with previous work (Benz et al, 2007; Leick et al., 2010; Xu et al., 2010a; Xu et al, 2010b). Linoleic acid is not synthesized by the pig, nor is it significantly modified prior to deposition (Ellis and McKeith, 1999), so it must be obtained from the diet. Diet composition easily affects the fatty acid composition in fat depots and skeletal muscle in growing-finishing pigs (Koch et al., 1968, Brooks, 1971; Nurmberg et al., 1998).

Linoleic acid is the predominant fatty acid found in DDGS, and represents approximately 60% of the fatty acid content in corn oil. Furthermore, C18:2 is preferentially deposited in pork adipose tissue (Koch, 1968), which explains why C18:2 content increases with the addition of DDGS to the diet.

These results indicate that feeding 30% DDGS diets to growing-finishing pigs negatively impacts the fatty acid composition of pork fat, which is primarily due to the relatively high concentration of linoleic acid. Although soft pork fat may be a concern for pork processors, the increase in PUFA levels in pork fat caused by DDGS inclusion may be beneficial to human health because increases in PUFA intake are linked to a reduction to coronary heart disease (Sanders, 2010). Furthermore, the addition of tallow did little to improve the overall fatty acid profile of backfat and belly fat because unsaturated fatty acids are preferentially deposited in adipose tissue.

Pork fat IV (Table 2.8), which is a measure of the ratio of unsaturated to saturated fatty acids, was increased in backfat for pigs fed diets containing DDGS compared to no DDGS ( $P < 0.01$ ), and was increased for pigs fed tallow diets compared to pigs not fed tallow containing diets ( $P < 0.01$ ). These responses agree with those reported by Feoli et al. (2007b) who observed an increase in IV when 2.5 or 5% tallow was added to 40% sorghum DDGS containing diets. A significant interaction ( $P < 0.03$ ) existed for belly fat IV where pigs fed D had the highest IV and pigs fed CON had the lowest IV. However, the IV for TD was greater than the CON but did not differ from T or D. It remains unclear why a DDGS x tallow interaction was detected for IV in belly fat and not backfat, but differences in lipogenic activity among adipose tissue sites may be responsible. It is known that lipogenesis is the first-limiting pathway in the storage of

body fat, and it is the most tightly regulated by alterations in energy intake (Vernon et al. 1999). Furthermore, feeding high fat diets has been shown to inhibit *de novo* fatty acid synthesis in pigs (Allee et al., 1971), which would allow for fat deposition to mimic the fatty acid profile of the diet. Comparing different sources of subcutaneous fat, Bee (2003) determined enzymatic activity of glucose-6-phosphate dehydrogenase, malic enzyme (both important enzymes that supply NADPH for the reductive biosynthesis of fatty acids), and fatty acid synthase (which catalyzes the synthesis of palmitate) were greater when a diet contained a high amount of DE (3,343 kcal/kg) compared to a lower DE (2,149 kcal/kg) diet. Therefore, in the present study, the calculated DE of the diets containing tallow was higher (4,125 kcal/kg) compared with diets not containing tallow (3,965 kcal/kg), which may lead to increased enzymatic activity in the adipose tissue. In contrast, Widmer et al. (2008) reported that IV of belly fat remained unaffected by DDGS inclusion. However, this may be explained due to the lower fat content of the control diets compared to the diets containing DDGS used in this study because 1% soybean oil was removed from the dietary formulation for each 10% DDGS added to the diet.

Belly fat IV is moderately, but positively correlated (0.49;  $P < 0.01$ ) to the phase 3 diet IV (Table 2.9). Backfat IV and the phase 3 diet was also strongly associated (0.81;  $P < 0.01$ ), which may be linked to the interaction observed between DDGS and tallow in backfat IV. These findings suggest and agree with previous research findings that unsaturated fatty acids are preferentially deposited in the backfat compared to other fat depots (Villegas, 1973).

#### *Objective and Subjective Fat Color Scores*

Fat color is an important quality characteristic that influences consumer buying decisions at the retail meat case. The addition of tallow to the diet did not impact objective nor subjective color scores of belly or backfat, and there were no DDGS × tallow interactions. However, the inclusion of 30% DDGS caused a reduction ( $P < 0.03$ ) in Hunter L\*, a\*, and b\* values and increases in Japanese Color Scores (Table 2.10). Simply, including 30% DDGS in the diet caused fat tissue to appear darker, more red, and more yellow compared to diets without DDGS. Although differences were detected, the range for all color values are similar to those previously reported (Widmer et al, 2008; Xu et al., 2010) and there are no specific industry standards for pork fat color. Lightness, or Hunter L\* values, were reduced in belly and backfat depots with the inclusion of 30% DDGS in the diets ( $P < 0.01$ ). Values for L\* range from 0 to 100 with 0 being black and 100 representing white. Therefore, lower L\* values indicate a darker color. Responses to changes in L\* values of backfat and belly fat have been inconsistent, but the inconsistency may relate to the source of DDGS, feeding duration, and amount fed. Widmer et al. (2008) observed a trend for decreased L\* in belly fat while increasing DDGS from 0 to 20% in the diet. Xu et al., (2010b) reported that belly fat L\* was not affected by DDGS level, but backfat L\* was reduced when pigs were fed 20 or 30% DDGS. Conversely, Leick et al. (2010) and Xu et al. (2010a) showed no differences in L\* values of belly fat due to the addition of up to 30% DDGS in corn-soybean meal diets.

Pigs fed D and TD had lower Hunter a\* in belly and backfat depots ( $P < 0.02$ ) compared to pigs fed CON and T, indicating that the fat color had lower red wavelengths. Others have reported no difference in a\* values while feeding DDGS (Widmer et al, 2008; Leick et al., 2010; Xu et al., 2010a; Xu et al., 2010b).

Also, in both belly and back fat depots, fat appeared less yellow according to the Hunter  $b^*$  values when D and TD were fed ( $P < 0.01$ ). Xu et al. (2010b) reported no difference in belly fat  $b^*$ , whereas backfat  $b^*$  was linearly increased with increasing dietary DDGS level, which is in disagreement with the present findings. In addition  $b^*$  values remained unaffected by dietary DDGS inclusion (Widmer et al., 2008; Xu et al., 2010a), and this response is different than the changes in  $b^*$  values in the current study. However, it is important to note that fat color is associated with the fatty acid composition. An increase in the amount of C18:2 and C18:3 in the diet can increase the yellow color of pork fat (Maw et al., 2003). Japanese color scores (1 = white, 4 = yellow) were higher, or more yellow, when pigs were fed D or TD ( $P < 0.03$ ) in both belly and backfat. However, previous researchers have reported no change in subjective color scores in backfat and belly fat from feeding diets containing up to 30% DDGS (Xu et al., 2010a; Xu et al., 2010b). Maw et al. (2003) suggested that an increase in fat yellowness is not due to the fatty acids themselves, because pure fatty acids remain colorless, but, rather is more likely due to an increase in the concentration of pigments such as carotenoids and xanthophylls which are associated with PUFA.

In summary, results from this study suggest that pigs fed a combination diet of 30% DDGS and 5% beef tallow had no difference in ADG, but tended to have reduced ADFI, without changes in G:F compared to pigs fed a corn-soybean meal diet. Furthermore, feeding diets containing 30% DDGS or 5% tallow resulted in no difference in HCW, carcass yield, backfat depth, loin depth, but less carcass fat free lean than pigs consuming a corn-soybean meal diet. Overall, pigs fed the combination of 30% DDGS and 5% tallow diets exhibited an increase in iodine value in belly and backfat depots

compared to the control diet, indicating that the dietary addition of tallow is ineffective in reducing pork fat IV in 30% DDGS diets. It is likely, the saturated fatty acid content of tallow and the amount included in the diet, was not great enough to offset the unsaturated fatty acids provided by DDGS.

**Table 2.1. Composition of DDGS and tallow (as-is basis)**

	DDGS	Tallow
Gross Energy, cal/g	N/A <sup>1</sup>	9428.00
Crude Protein, %	26.33	N/A
Moisture, %	13.73	N/A
Crude Fat, %	11.12	99.96
Crude Fiber, %	5.82	N/A
Ash, %	4.25	N/A
Lysine, %	0.96	N/A
MIU <sup>2</sup> , %	N/A	0.42

<sup>1</sup>N/A= Not analyzed

<sup>2</sup>MIU = moisture, impurities, unsaponifiables

**Table 2.2. Fatty acid profile of DDGS and tallow, fatty acids as a % of crude fat (as-is basis)**

	DDGS	Tallow
Crude fat, %	11.12	99.96
C14:0, %	0.05	2.51
C16:0, %	14.00	23.23
C16:1, %	0.14	2.72
C18:0, %	1.89	20.17
C18:1, %	25.16	43.93
C18:2, %	55.76	3.91
C18:3, %	1.42	0.21
C20:0, %	0.41	0.16
C20:1, %	0.29	0.26
C20:2, %	0.04	0.07
C22:0, %	0.16	0.02
C22:1, %	0.25	0.00
C24:0, %	0.23	<0.01

**Table 2.3. Composition of diets (as-fed basis)**

Ingredient, %	Phase 1 (30 to 60 kg)				Phase 2 (60 to 90 kg)				Phase 3 (90 to 120 kg)			
	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>
Corn	71.85	64.05	47.00	39.50	79.45	72.40	54.90	47.65	84.48	79.30	61.80	54.65
Soybean Meal	25.50	28.30	20.75	23.25	18.10	20.15	13.0	15.25	11.00	13.20	6.10	8.25
DDGS	0.00	0.00	30.00	30.00	0.00	0.00	30.00	30.00	0.00	0.00	30.00	30.00
Beef Tallow	0.00	5.00	0.00	5.00	0.00	5.00	0.00	5.00	0.00	5.00	0.00	5.00
Limestone	0.70	0.70	1.30	1.30	0.55	0.55	1.15	1.15	0.57	0.55	1.15	1.15
Dicalcium Phosphate	1.00	1.00	0.00	0.00	0.95	0.95	0.00	0.00	1.00	1.00	0.00	0.00
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-lysine	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
VTM premix <sup>2</sup>	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

<sup>1</sup>CON = corn-soybean meal control diet, T = CON and 5% tallow, D = CON plus 30% DDGS, TD = CON plus 5% tallow and 30% DDGS.

<sup>2</sup>Premix supplied the following per kg of diet: vitamin A, 11,000 IU; vitamin D<sub>3</sub>, 2,756 IU; vitamin E, 55 IU; vitamin B<sub>12</sub>, 55µg; riboflavin, 16,000 mg; pantothenic acid, 44.1 mg; niacin, 82.7 mg; Zn, 150 mg; Fe, 175 mg; Mn, 60 mg; Cu, 17.5 mg; I, 2 mg; and Se, 0.3 mg.

**Table 2.4. Nutrient composition of diets (as-fed basis)**

Calculated	Phase 1 (30 to 60 kg)				Phase 2 (60 to 90 kg)				Phase 3 (90 to 120 kg)			
	CON <sub>1</sub>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>
ME, Mcal/kg	3.32	3.53	3.31	3.53	3.33	3.54	3.32	3.53	3.33	3.54	3.33	3.54
Crude Fat, %	3.57	3.35	5.79	5.57	3.64	3.43	5.87	5.65	3.70	3.49	5.93	5.71
C18:2, %	1.64	1.70	2.97	3.03	1.74	1.81	3.07	3.13	1.79	1.90	3.16	3.22
SID Lys, %	0.95	1.01	0.96	1.01	0.77	0.81	0.76	0.81	0.59	0.63	0.59	0.63
SID Lys:ME	2.86	2.86	2.90	2.86	2.31	2.29	2.29	2.30	1.77	1.78	1.77	1.783
Analyzed												
Moisture, %	12.96	11.90	15.16	12.55	13.14	13.05	13.66	11.41	13.54	13.74	20.44	9.53
Crude Protein, %	17.2	17.25	21.57	21.00	14.02	13.90	18.01	18.16	11.06	12.05	15.53	15.89
Crude Fat, %	2.76	7.39	4.60	8.94	2.45	6.30	5.09	8.49	2.78	6.98	4.56	9.10
Crude Fiber, %	2.10	2.02	3.40	3.26	1.64	1.78	3.12	2.89	1.59	1.63	3.05	2.99
NDF, %	7.65	7.85	17.27	15.71	7.18	7.45	15.89	14.08	8.25	8.60	16.78	16.71
Ash, %	4.87	4.96	5.43	5.08	4.09	3.89	4.61	5.06	3.63	3.74	3.92	4.21
Linoleic Acid, %	1.72	1.58	3.06	3.25	1.62	1.87	2.90	3.14	2.09	2.22	3.53	3.45

<sup>1</sup>CON = corn-soybean meal control diet, T = CON and 5% tallow, D = CON plus 30% DDGS, TD = CON plus 5% tallow and 30% DDGS.

**Table 2.5. Effects of tallow and DDGS on pig growth performance**

Trait	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>	PSE	DDGS	Tallow	Gender	DDGS×Tallow
Initial BW, kg	32.70	31.95	32.59	32.38	0.70	NS <sup>2</sup>	NS	NS	NS
Final BW, kg	112.69	114.55	112.59	113.27	1.158	NS	NS	<0.01	NS
Phase 1									
ADG, kg	0.99	1.01	0.96	1.01	0.02	NS	<0.02	<0.09	NS
ADFI, kg	2.22 <sup>ax</sup>	2.13 <sup>a</sup>	2.29 <sup>ay</sup>	2.02 <sup>b</sup>	0.04	NS	<0.01	<0.05	<0.04
G:F	0.45 <sup>ax</sup>	0.47 <sup>by</sup>	0.42 <sup>a</sup>	0.50 <sup>bx</sup>	0.01	NS	<0.01	NS	<0.01
Phase 2									
ADG, kg	1.04	1.11 <sup>x</sup>	1.07	1.02 <sup>y</sup>	0.02	NS	NS	<0.01	<0.02
ADFI, kg	2.98	2.81	2.87	2.65	0.04	<0.01	<0.01	<0.01	NS
G:F	0.35 <sup>a</sup>	0.39 <sup>bc</sup>	0.37 <sup>ac</sup>	0.39 <sup>bc</sup>	0.01	NS	<0.01	NS	<0.10
Phase 3									
ADG, kg	1.00	1.01	0.99	1.00	0.02	NS	NS	<0.01	NS
ADFI, kg	3.06	2.77	3.11	2.69	0.06	NS	<0.01	<0.01	NS
G:F	0.33	0.37	0.32	0.37	0.01	NS	<0.01	NS	NS
Overall									
ADG, kg	1.01	1.04	1.01	1.01	0.03	NS	NS	<0.01	NS
ADFI, kg	2.76 <sup>a</sup>	2.59 <sup>bc</sup>	2.76 <sup>a</sup>	2.45 <sup>bd</sup>	0.01	<0.04	<0.01	<0.01	<0.06
G:F	0.37	0.40	0.37	0.41	<0.01	NS	<0.01	NS	NS

<sup>1</sup>CON = corn-soybean meal control diet, T = CON and 5% tallow, D = CON plus 30% DDGS, TD = CON plus 5% tallow and 30% DDGS.

<sup>2</sup>NS = Non-significant (P > 0.10).

<sup>a,b,c</sup> Within a row, means without a common superscript differ (P < 0.05)

<sup>x,y</sup> Within a row, means without a common superscript differ (0.05 < P < 0.10)

**Table 2.6. Effects of tallow and DDGS on carcass characteristics**

Trait	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>	PSE	DDGS	Tallow	Gender	DDGS×Tallow
Hot carcass weight, kg	88.58	91.62	88.35	89.37	1.05	<0.08	<0.01	<0.01	NS <sup>2</sup>
Carcass yield, %	78.77	79.55	78.34	79.35	0.19	NS	<0.01	NS	NS
Backfat depth <sup>3</sup> , cm	2.00	2.19	1.91	2.04	0.05	<0.02	<0.01	<0.01	NS
Loin depth, cm	6.99	6.71	6.71	6.74	0.11	NS	NS	NS	NS
Carcass fat-free lean, %	54.99 <sup>a</sup>	53.99 <sup>bc</sup>	54.73 <sup>a</sup>	54.50 <sup>ac</sup>	0.19	NS	<0.01	<0.02	<0.04

<sup>1</sup>CON = corn-soybean meal control diet, T = CON and 5% tallow, D = CON plus 30% DDGS, TD = CON plus 5% tallow and 30% DDGS.

<sup>2</sup>NS = Non-significant (P > 0.10).

<sup>3</sup>Backfat depth measured at the 10<sup>th</sup> rib

<sup>a,b,c</sup> Within a row, means without a common superscript differ (P < 0.05)

**Table 2.7. Effects of tallow and DDGS on belly characteristics**

Trait	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>	PSE	DDGS	Tallow	Gender	DDGS× Tallow
Belly flop angle, °	133.96	113.42	71.75	57.73	9.56	<0.01	<0.09	NS	NS
Belly thickness, cm	3.34	3.64	3.61	3.75	0.12	NS	<0.07	<0.04	NS
Belly length, cm	58.28	57.34	58.23	56.46	0.63	NS	<0.04	NS	NS
Belly fat IV	59.01 <sup>a</sup>	64.22 <sup>x</sup>	71.22 <sup>b,y</sup>	67.88 <sup>b</sup>	1.87	<0.01	NS	<0.05	<0.03
Backfat IV	56.72	61.90	68.31	71.78	1.40	<0.01	<0.01	NS	NS

<sup>1</sup>CON = corn-soybean meal control diet, T = CON and 5% tallow, D = CON plus 30% DDGS, TD = CON plus 5% tallow and 30% DDGS.

<sup>2</sup>NS = Non-significant (P > 0.10).

<sup>a,b</sup> Within a row, means without a common superscript differ (P < 0.05)

<sup>x,y</sup> Within a row, means without a common superscript differ (0.05 < P < 0.10)

**Table 2.8. Effects of tallow and DDGS on belly and backfat fatty acid composition**

Trait	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>	PSE	DDGS	Tallow	Gender	DDGS×Tallow
Belly fatty acid, %									
C 16:0	23.29 <sup>a</sup>	20.39 <sup>b</sup>	22.13	20.15 <sup>b</sup>	0.91	NS	<0.01	NS	NS
C 16:1	2.98	3.07	2.40	2.46	0.29	<0.04	NS	NS	NS
C 18:0	13.63 <sup>a,x</sup>	12.20	11.61 <sup>y</sup>	11.37 <sup>b</sup>	0.56	<0.02	NS	NS	NS
C 18:1	45.23 <sup>a</sup>	50.90 <sup>b</sup>	43.36 <sup>a</sup>	47.54		<0.08	<0.01	NS	NS
C 18:2	8.49 <sup>a</sup>	8.85 <sup>a</sup>	16.41 <sup>b</sup>	15.67 <sup>b</sup>	1.12	<0.01	NS	NS	NS
SFA <sup>3</sup>	38.93 <sup>a</sup>	34.05 <sup>b</sup>	34.13 <sup>b</sup>	32.40 <sup>b</sup>	1.09	<0.01	<0.01	NS	NS
MUFA <sup>4</sup>	51.08	57.47 <sup>a</sup>	48.65 <sup>b</sup>	56.24 <sup>a</sup>	2.10	NS	<0.01	NS	NS
PUFA <sup>5</sup>	8.51 <sup>a</sup>	9.19 <sup>a</sup>	17.23 <sup>b</sup>	16.08 <sup>b</sup>	1.23	<0.01	NS	NS	NS
Backfat fatty acid, %									
C 16:0	24.49 <sup>a</sup>	21.99 <sup>b</sup>	23.60 <sup>c</sup>	20.32 <sup>b,d</sup>	0.66	<0.07	<0.01	NS	NS
C 16:1	1.60	1.59	1.88	1.09	0.27	NS	NS	NS	NS
C 18:0	18.04 <sup>a</sup>	14.15 <sup>b</sup>	16.70	14.25 <sup>b</sup>	0.88	NS	<0.01	NS	NS
C 18:1	43.90 <sup>a,x</sup>	46.64 <sup>a,y</sup>	39.86 <sup>b</sup>	44.82 <sup>a</sup>	0.78	<0.01	<0.01	NS	NS
C 18:2	8.81 <sup>a</sup>	9.65 <sup>a</sup>	18.04 <sup>b</sup>	18.40 <sup>b</sup>	0.98	<0.01	NS	NS	NS
SFA <sup>3</sup>	42.79 <sup>a</sup>	37.89	39.77 <sup>a</sup>	33.11 <sup>b</sup>	1.60	<0.01	<0.01	NS	NS
MUFA <sup>4</sup>	48.39 <sup>a,d</sup>	53.96 <sup>b</sup>	42.66 <sup>c</sup>	47.12 <sup>d</sup>	1.01	<0.01	<0.01	NS	NS
PUFA <sup>5</sup>	8.89 <sup>a</sup>	9.92 <sup>a</sup>	18.05 <sup>b</sup>	18.45 <sup>b</sup>	1.00	<0.01	NS	NS	NS

<sup>1</sup>CON = corn-soybean meal control diet, T = CON and 5% tallow, D = CON plus 30% DDGS, TD = CON plus 5% tallow and 30% DDGS.

<sup>2</sup>NS = Non-significant (P > 0.10).

<sup>3</sup>SFA = Saturated fatty acids

<sup>4</sup>MUFA = Monosaturated fatty acids

<sup>5</sup>PUFA = Polyunsaturated fatty acids

<sup>a,b,c,d</sup> Within a row, means without a common superscript differ ( $P < 0.05$ )

<sup>x,y</sup> Within a row, means without a common superscript differ ( $0.05 < P < 0.10$ )

**Table 2.9. Correlation of belly fat and backfat IV to Phase 3 diet IV**

	Pearson Correlation Coefficient	P-value
Belly fat IV and diet IV	0.49	< 0.01
Backfat IV and diet IV	0.81	< 0.01

**Table 2.10. Effects of tallow and DDGS on belly and backfat color characteristics**

Trait	CON <sup>1</sup>	T <sup>1</sup>	D <sup>1</sup>	TD <sup>1</sup>	PSE	DDGS	Tallow	Gender	DDGS× Tallow
<b>Belly fat</b>									
L* <sup>3</sup>	72.31 <sup>a</sup>	72.26 <sup>c</sup>	69.62 <sup>b,d</sup>	70.46	0.61	<0.01	NS	NS	NS
a* <sup>4</sup>	-0.55 <sup>x</sup>	-0.51 <sup>a</sup>	-0.72	-1.07 <sup>y,b</sup>	0.14	<0.02	NS	<0.02	NS
b* <sup>5</sup>	4.17	4.44 <sup>a</sup>	3.46	3.16 <sup>b</sup>	0.31	<0.01	NS	<0.04	NS
JCS <sup>6</sup>	2.05	2.10	2.46	2.50	0.18	<0.03	NS	NS	NS
<b>Backfat</b>									
L* <sup>3</sup>	71.10 <sup>a</sup>	69.33	66.61 <sup>b</sup>	66.41 <sup>b</sup>	1.05	<0.01	NS	NS	NS
a* <sup>4</sup>	-0.83 <sup>a</sup>	-0.93 <sup>x</sup>	-1.35 <sup>b,y</sup>	-1.40 <sup>b,y</sup>	0.12	<0.01	NS	NS	NS
b* <sup>5</sup>	4.31 <sup>a</sup>	3.85 <sup>c</sup>	3.10 <sup>d</sup>	2.66 <sup>b,d</sup>	0.30	<0.01	<0.10	NS	NS
JCS <sup>6</sup>	2.44 <sup>a</sup>	2.51 <sup>x</sup>	2.95 <sup>b,y</sup>	2.83	0.13	<0.01	NS	NS	NS

<sup>1</sup>CON = corn-soybean meal control diet, T = CON and 5% tallow, D = CON plus 30% DDGS, TD = CON plus 5% tallow and 30% DDGS.

<sup>2</sup>NS = Non-significant (P > 0.10).

<sup>3</sup>L\* = Hunter Miniscan lightness

<sup>4</sup>a\* = Hunter Miniscan redness

<sup>5</sup>b\* = Hunter Miniscan yellowness

<sup>6</sup>JCS = Japanese Color Score

<sup>a,b,c,d</sup> Within a row, means without a common superscript differ (P < 0.05)

<sup>x,y</sup> Within a row, means without a common superscript differ (0.05 < P < 0.10)

## **CHAPTER 3**

### **Effects of adding supplemental tallow to diets containing DDGS on fatty acid digestibility in growing pigs**

## **OVERVIEW:**

An experiment was conducted to determine the ileal and fecal digestibility of fatty acids in diets containing 2 levels of DDGS (0 or 30%) and 3 levels of tallow (0, 5, or 10%). A total of 24 barrows were surgically fitted with a T-cannula at the distal ileum. Pigs were randomly assigned to one of six different dietary treatments. Diets were formulated to contain a constant SID Lys to ME ratio. Celite was added to the diets at 0.3% as an indigestible marker. Dietary treatments consisted of the following: corn-soybean meal control (CON), CON plus 5% tallow (5T0D), CON plus 10% tallow (10T0D), CON plus 30% DDGS (0T30D), CON plus 30% DDGS and 5% tallow (5T30D), and CON plus 30% DDGS and 10% tallow (10T30D). Eight replications per treatment were achieved by randomizing diets among pigs for a second collection period. Feed was supplied at a daily level equivalent to 3 times the maintenance ME requirement and was divided into two equal meals per day. Each pig was fed their respective diet for a 5-d adaptation period, with 3-d fecal, and 2-day digesta collection periods. Collections occurred from 0800 to 1200 h and from 1600 to 2000 h. All samples were immediately frozen at -18°C. Digesta samples were pooled within pig and freeze-dried for analysis. Digestibility was determined using the index method. Significant interactions between DDGS and tallow were observed for all fatty acids ( $P < 0.05$ ), except for fecal C18:2 and fecal PUFA digestibility, which were not affected by dietary treatment. Fecal MUFA digestibility ranged from 88.18 to 96.46%, and was highest for 5T0D (94.97%) and 10T0D (96.40%) and lowest for CON (88.18%) and 0T30D (89.18%;  $P < 0.05$ ). Conversely, fecal SFA digestibility was more variable among dietary treatments ranging from 64.78 to 85.41%. It was lowest for 0T30D, 5T30D, and 10T30D (64.78, 66.29,

66.70%, respectively), and highest for 5T0D and 10T0D (80.70, 85.41%, respectively;  $P < 0.05$ ). Ileal digestibility of MUFA ranged from 74.42 to 85.95%, and was lowest for CON (74.42%), but highest for 10T0D (85.95%;  $P < 0.05$ ). Ileal PUFA digestibility ranged from 57.37 to 77.28% and was lowest for 10T30D (57.37%) and highest for CON (76.00%;  $P < 0.05$ ), even though DDGS contains a high proportion of PUFA. The amount of digestible fatty acids increased with the addition of DDGS and tallow regardless of digestibility. Amounts of digestible MUFA and PUFA digested increased when DDGS ( $P < 0.01$ ) and tallow ( $P < 0.01$ ) were included in the diet compared to when either ingredient was excluded. These increases in digestible MUFA are a reflection of the MUFA and PUFA concentration in the diet. For digestible SFA, an interaction ( $P < 0.01$ ) between DDGS and tallow was observed. Diets containing 10% tallow, with or without DDGS, contained the greatest concentration of digestible SFA (3.32 and 3.41%) compared with all other diets (0.63 to 2.18%). Although combining 5 or 10% tallow and 30% DDGS generally reduced the digestibility of nearly all fatty acids compared to CON and 0T30D, the amount of fatty acids digested mimics the fatty acid profile of the diet indicating that the amount of fatty acids digested is a function of the amount of fatty acids in the diet.

**Key words:** DDGS, fatty acid digestibility, tallow

## INTRODUCTION

As U.S. ethanol production has increased in recent years, so has the production and utilization of corn co-products, such as dried distillers grains with solubles (DDGS), in swine diets. However, as the concentration of DDGS increases in growing-finishing

swine diets, pork fat quality is negatively affected (Widmer et al., 2008; Xu et al., 2010). Specifically, when high levels of DDGS are included in the diet, polyunsaturated fatty acids (PUFA), C18:2 content, and iodine value (IV) of pork fat are increased (Stein and Shurson, 2009; Xu et al., 2010b). Consequently, Xu et al. (2010b) and Widmer et al. (2008) have demonstrated that belly firmness is reduced when high levels of DDGS are included in grower-finisher diets. However, because tallow is an economical and readily available saturated animal fat source, it may override the negative consequences associated with feeding high levels of DDGS and improve pork fat quality.

Because the composition of dietary fat directly affects the fatty acid composition of pork fat (Koch et al., 1968; Brooks, 1971; Nurmberg et al., 1998), it is essential to determine fatty acid digestibility in DDGS diets to more fully understand changes that occur in pork fat quality when DDGS is fed to growing-finishing pigs. No data have been published related to the digestibility of fatty acids in corn DDGS for swine. However, Stein (2009) reported the digestibility coefficients of acid-hydrolyzed ether extract and found that high protein DDGS and conventional DDGS had greater digestibility of fat than high oil corn and corn germ, which suggests that the fermentation process in ethanol production may increase fat digestibility. Stein and Shurson (2009) reported that DDGS contains approximately 25.3% NDF. Urriola et al. (2010) reported that apparent total tract digestibility (ATTD) of NDF among 8 corn DDGS sources averaged 59.3%, but ranged from 51.6 to 65.8%, and ATTD of total dietary fiber ranged from 39.4 to 56.4%. These results indicate that considerable variability in fiber digestibility exists among DDGS sources, which is likely a significant contributing factor to the variability in DE and ME content. Several researchers have shown that apparent fat

digestibility is significantly reduced when dietary fiber increases (Dierick et al., 1989; Noblet and Shi, 1993; Shi and Noblet, 1993). Although several reports have been published regarding the fatty acid digestibility of beef tallow in swine diets (Ozimeck et al., 1984; Duran-Montge et al., 2007; Mitchaonthai et al., 2008), the interactive effects between DDGS and tallow on fatty acid digestibility are unknown. By understanding these interactive effects, it may provide useful information to predict pork fat quality effects when growing-finishing pigs are fed diets containing DDGS and tallow. Therefore, the objective of this study was to determine the effects of increasing dietary levels of DDGS and tallow on ileal and fecal fatty acid digestibility in growing pigs.

## **MATERIALS AND METHODS**

### *Animals and Housing*

The University of Minnesota Institutional Animal Care and Use Committee approved all procedures for this experiment. A total of 28 barrows (initial BW = 25 kg) from Landrace × Yorkshire sows (Topigs, Winnipeg, Manitoba, Canada) and Duroc boars (Comparts Boar Store, Nicollet, MN) were surgically fitted with a T-cannula at the distal ileum following procedures similar to Jendza et al. (2011) and Dilger et al. (2004). Following surgery, pigs were housed in individual metabolism stalls for a minimum of 2 wk to allow for recuperation before initiating the experiment. Pigs were slowly reintroduced to feed during the recuperation period, and had near *ad libitum* access by the end of the 2-wk period. Four of the 28 pigs served as replacements to account for the possibility of unretained cannulas, poor recovery, or death of cannulated pigs.

### *Cannulation procedure*

Feed was withdrawn 18 to 24 h prior to surgery. Sedation was achieved by

injecting a cocktail mixture of Telazol (1.1 mg each of tiletamine and zolazepam/kg BW; Pfizer, New York, NY), ketamine (1.1 mg/kg BW; Pfizer, New York, NY), and xylazine (1.1 mg/kg BW; Lloyd Inc., Shenandoah, IA) administered at 0.044 mL/kg BW. Induction of anesthesia was maintained with 2% isoflurane and oxygen at 1.0-1.2 L/min. Surgery procedures were similar to Jendza et al. (2011) and Dilger et al. (2004), but varied slightly. In the present experiment, an incision approximately 10 cm parallel and caudal to the last rib was made on the right side of the pig. The ileocecal junction was located, exteriorized, and a 4 cm incision was made approximately 5 cm cranial to the ileocecal junction. A stainless steel T-cannula was inserted into the distal ileum and a purse stitch was used to anchor the cannula and close the intestine. A small (2 cm) incision was created between the last second and third ribs. The cannula was carefully excised through the fistula. Once through the skin, the wings of the cannula were checked so they followed the contours of the ribs. Two round washers were placed on the cannula, and the cannula was capped. The main incision was closed in 3 layers utilizing a continuous stitch, and the last layer was closed with a subcuticular stitch which resulted in no external suture, thus minimizing the risk of bacterial infection.

### *Diets*

The DDGS source used in this study was obtained from Absolute Energy, LLC (Lyle, MN) and tallow was sourced from Origo (New Ulm, MN). Before diet formulation, proximate analysis (moisture, NFTA 2.2.2.5; Ash, AOAC 923.03; crude fat, AOAC 920.39; crude fiber, AOAC 962.09; crude protein, AOAC 990.03), mycotoxins (AOAC 991.31), and fatty acid profile (AOCS 996.06) analysis were conducted for DDGS (Table 3.1) at Minnesota Valley Testing Laboratories (New Ulm, MN), and amino acid levels (AOAC 982.30 E [a,b,c]) were assessed by the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia,

MO). The fatty acid profile of tallow was analyzed (AOCS 996.06) by Minnesota Valley Testing Laboratories (New Ulm, MN). Analyzed nutrient values for DDGS (26.17% crude protein, 10.66% moisture, 11.14% crude fat, 6.93% crude fiber, 4.34% ash, 0.95% lysine) and tallow were used in diet formulation, with the following assumptions for digestibilities of nutrients: lysine, 63%; methionine, 82%; tryptophan, 69%; threonine, 71% (Urriola, 2007); and available phosphorus 77% (NRC, 1998).

Six experimental diets (Table 3.2, Table 3.3) were formulated to contain two levels of DDGS (0 or 30%) and three levels of tallow (0, 5, 10%). Diets consisted of the following: corn-soybean meal control (CON), CON plus 5% tallow (5T0D), CON plus 10% tallow (10T0D), CON plus 30% DDGS (0T30D), CON plus 30% DDGS plus 5% tallow (5T30D), and CON plus 30% DDGS plus 10% tallow (10T30D). All diets were formulated to contain similar ME:standardized ileal digestible (SID) Lys and available phosphorus content. All other nutrients met or exceeded NRC (1998) recommendations for 40 kg pigs. Celite was added at a level of 0.3% to all diets as an indigestible marker to increase the acid insoluble ash content of diet. Feed was supplied to pigs at a daily level equivalent to 3 times the maintenance energy requirement (106 kcal ME/kg BW<sup>0.75</sup>). This daily amount was divided into two equal meals supplied at 0800 and 1600 h. Each pig was fed their corresponding diet for a 5-d adaptation period.

#### *Sample Collection and Chemical Analysis*

Fecal samples, using the grab sample technique, were collected on d 6, 7, and 8, immediately after the morning and evening feedings. Rectal palpation was performed to ensure a fresh fecal sample. Fecal samples were pooled by animal and immediately frozen at -18° C until analysis was conducted. Samples were dried at 55° C in a forced draft oven and ground to pass through a 1 mm screen for fatty acid analysis.

Ileal digesta samples were collected on d 9 and 10 for two- 4 h periods throughout the collection days. Collections occurred from 0800 to 1200 h and from 1600 to 2000 h. Immediately following a feeding, cannulas were opened and a 500 ml Whirl-pak bag containing 10 ml of a 10% formic acid solution was attached to the cannula barrel with a rubber band. Bags were removed when half-full or at 30 min intervals, whichever came first. All samples were immediately frozen in -18° C. Digesta samples were pooled within pig and freeze-dried for analysis.

Feed, feces, and digesta samples were analyzed for acid insoluble ash and fatty acid content. Acid insoluble ash was determined where a 5 g sample was digested in HCl, filtered and washed with boiling distilled water, and ashed in a 600° C oven (AOAC 942.05). Fatty acid analysis of diets, feces and ileal digesta was performed commercially (Lipid Technologies, LLC, Austin, MN) using gas chromatography to separate fatty acid methyl esters according to the AOCS (1998) method Ce 1-62. All fatty acids from C12:0 to C24:1 were measured.

#### *Calculations and Statistical Analysis*

Digestibility values were calculated based on the index method utilizing the following equation where feces could be interchanged for digesta:

$$\text{Digestibility, \%} = 100 - \left[ 100 \times \left( \frac{[\text{index in feed}] \times [\text{component in feces}]}{[\text{index in feces}] \times [\text{component in feed}]} \right) \right]$$

Amount of digestible fatty acids was determined by multiplying the amount of fatty acid in the diet by apparent ileal digestibility coefficient for each individual fatty acid.

Each pig was used as the experimental unit for all data analysis. All analyses were conducted utilizing the Mixed Procedure of SAS (SAS Inst. Inc., Cary, NC).

Dietary treatments were arranged in a  $2 \times 3$  factorial arrangement with fixed effects of DDGS, tallow, and DDGS  $\times$  tallow interaction. The significance level was declared at  $P < 0.05$  and trends are described at  $0.10 > P > 0.05$ . The pdiff option with Tukey adjustment was used for comparison of treatment least squares means.

## **RESULTS AND DISCUSSION**

### *Fecal Digestibility*

Fecal fatty acid digestibility was generally greater than ileal digestibility (Table 3.4), which agrees with previous research results where fecal digestibility values were greater compared to ileal digestibility values when tallow was included in the diet (Duran-Montge et al., 2007; Ozimek et al., 1984). Fatty acids from C12:0 to 24:1 were measured. Of primary interest were the four predominate fatty acids (C16:0, C18:0, C18:1, and C18:2) found in swine diets, along with the collection of MUFA, PUFA, and SFA. The remaining fatty acids were found in low quantities ( $< 2.5\%$  of total lipid profile) in the diet and are not discussed (C14:0, 16:1; C18:3; C18:4. C20:0, C20:1, C20:4, C20:5, C22:0, C22:1;C24:0)

An interaction ( $P < 0.01$ ) between DDGS and tallow was observed for fecal C16:0 digestibility, which suggests that feeding diets containing DDGS and tallow reduces digestibility of C16:0 compared to pigs fed no DDGS and no tallow. Furthermore, pigs fed 30% DDGS and 5% tallow had reduced concentrations of C16:0 in both belly and backfat depots compared to pigs fed the control diet, which is likely due to the lower digestibility of C16:0 (Pomeranke, 2012, unpublished). Furthermore, main effects of DDGS and tallow were observed. The addition of 30% DDGS also caused a reduction in C16:0 digestibility compared to pigs not receiving diets containing 30% DDGS. The

results from the present experiment agree with previous results (Ozimek et al., 1984; Duran-Montge et al., 2007; Mitchaothai et al., 2007) suggesting that C16:0 fecal digestibility is greater from tallow compared to other vegetable based sources including: rapeseed oil, sunflower oil, or linseed oil. Fecal digestibility of C16:0 decreased ( $P < 0.01$ ) when tallow was included in the diet, compared to when tallow was absent from the diets.

Similar to C16:0 fecal digestibility, a significant interaction was detected between DDGS and tallow ( $P < 0.01$ ) for C18:0, where diets containing tallow had greater digestibility compared to CON or OT30D. Diets containing both DDGS and tallow had lower fecal digestibility compared to tallow diets without DDGS. Pigs fed CON had greater C18:0 deposited in their belly and backfat compared to all other treatments (Pomeranke, 2012, unpublished), which is surprising because we observed a negative digestibility value for C18:0 in the CON diet. The negative value is likely the result of a low C18:0 concentration in the diet (Table 3.4) along with endogenous fat secretion from mucosa cells in the colon, sloughing of endoepithelial cells, or *de novo* synthesis (Overland et al., 1994). The inclusion of 30% DDGS in diets resulted in an increase ( $P < 0.01$ ) in fecal C18:0 digestibility compared to pigs consuming diets with no DDGS. Likewise, when tallow was included in the diet, digestibility of C18:0 increased ( $P < 0.01$ ) compared to when tallow was not included in the diets. These results are in agreement with previous results (Ozimek et al., 1984; Duran-Montge et al., 2007; Mitchaothia et al., 2007; Mitchaothia et al., 2008) where fecal C18:0 digestibility was greater when diets contained tallow compared to control or vegetable oil-supplemented diets (sunflower, linseed, or rapeseed oil).

A significant interaction existed for fecal C18:1 ( $P < 0.01$ ). The CON and 5T30D had the lowest digestibility of C18:1 compared to diets containing only tallow or DDGS. However, when tallow was included in the diets without DDGS, digestibility increased compared to CON. Surprisingly, pigs fed the 30% DDGS diet exhibited a C18:1 digestibility similar to those fed the 5 and 10% tallow diets (97.7, 97.5, 98.0%, respectively). It is possible that the fiber fraction in DDGS is responsible for the reduced C18:1 digestibility. Stein (2009) found that acid-hydrolyzed ether extract of corn oil is more digestible than intact forms of oils. However, of intact fat sources, high protein DDG and DDGS had greater digestibility of fat compared to high oil corn and corn germ. This suggests, that in DDGS, the fermentation process for ethanol production may have liberated some oil or made fat slightly more digestible in DDGS compared to high oil corn and corn germ. Intact fat sources, such as corn germ meal or DDGS, may have lower digestibility values because digestive enzymes may not have access to the lipid substrate because carbohydrate molecules, specifically fiber, may block access to the digestive lipase (Stein, 2009). Oleic acid (C18:1) is one of the predominant fatty acids in pork fat. Furthermore, it is the main fatty acid in beef tallow. In DDGS, C18:1 is typically the second most abundant fatty acid following C18:2. Regardless, a significant main effect of the addition of DDGS to the diet was not detected in the present study. However, the main effect of adding tallow to the diet increased fecal C18:1 digestibility ( $P < 0.01$ ) compared with diets not containing tallow. The increased C18:1 fecal digestibility response due to tallow addition to the diet is not in agreement with some results, but in agreement with others in the published literature. When Duran-Montge et al. (2007) fed diets containing 10% tallow, digestibility of C18:1 increased compared to

control and linseed oil containing diets. However, when Mitchaothia et al. (2007) fed 5% tallow diets, digestibility decreased compared to a diet containing sunflower oil. The discrepancy between previously reported fecal C18:1 digestibility responses may relate to the basal ingredients of the diets, barley (Duran-Montge et al., 2007) vs. cassava chips and soybean meal (Mitchaothia et al., 2007), or the concentration of tallow in the diets. Furthermore, the differences in responses may be due to the differences in the type and level of fiber due to an interaction between fat and fiber components.

MUFA represent over 50% of the fatty acids in pork fat depots (Xu et al., 2010), and represents approximately one-third of the fatty acids in diets. An interaction between DDGS and tallow existed for MUFA fecal digestibility ( $P < 0.01$ ). Regardless of dietary DDGS inclusion, adding 5 or 10% tallow to diets increased fecal MUFA digestibility compared with CON or 30% DDGS diets. However, when increasing levels of tallow were added to 30% DDGS diets, fecal digestibility was not as great (91.4 and 93.3%, respectively) compared with when DDGS was absent from the diet (5T0D, 10T0D; 95.0, 96.4, respectively). Main effects of DDGS ( $P < 0.01$ ) and tallow ( $P < 0.01$ ) were detected for MUFA. The dietary addition of DDGS decreased fecal MUFA digestibility, whereas adding supplemental tallow increased MUFA digestibility. Contrary to the present results, Mitchaothia et al. (2007) found a decrease in MUFA digestibility with the addition of tallow compared to a cassava chip-soybean meal diet supplemented with sunflower oil which suggests that the fatty acid profile of ingredients ultimately impact digestibility.

For SFA, an interaction between DDGS and tallow was also observed ( $P < 0.01$ ). With increasing levels of tallow in diets without DDGS (5T0D, 10T0D), fecal SFA

digestibility increased (80.7, 85.4%, respectively) compared to the control diet (65.4%). However, when DDGS and increasing levels of tallow were added to the diet (5T30D, 10T30D), fecal digestibility of SFA was not different compared to when DDGS was not present in the diet. The addition of 30% DDGS resulted in a reduction in SFA digestibility ( $P < 0.01$ ), whereas diets lacking DDGS had an increase in SFA digestibility. Furthermore, 5 or 10% dietary inclusion of tallow increased SFA digestibility ( $P < 0.01$ ). Mitchaothai et al. (2007) suggested that pigs fed diets supplemented with sunflower oil compared to tallow had an increased digestibility of unsaturated fatty acids because micelles are formed more easily. The position of the fatty acid on the triglyceride also plays an important role because fatty acids at the 2-position are better digested than those at the 1 and 3- positions (Bracco, 1994, Nelson and Innis, 1999). Thus, the resulting 2-monoglycerol is efficiently incorporated into the micelle (Lien, 1994). Sunflower oil is similar in composition to corn oil, with corn oil being higher in C18:2 and sunflower oil being higher in C18:1, suggesting that the same relationship described by Mitchaothai may also apply to DDGS.

#### *Apparent Ileal Fatty Acid Digestibility and Amount of Digestible Fatty Acids in Diets*

Ileal digestibilities are superior to fecal digestibility fatty acid values when fish oil, rapeseed oil, or coconut oil are fed (Jorgensen et al., 2000), but fecal digestibilities are greater than ileal digestibilities when tallow is included in the diet (Duran-Montge et al., 2007; Ozimeck et al., 1984). These differences are likely due to the saturation of the fatty acid, with unsaturated fatty acids having higher digestibility compared to saturated fatty acids (Jorgensen et al., 1993; Overland et al., 1994). Furthermore, fecal digestibility coefficients are greater compared to ileal digestibilities due to the contribution of

phospholipids to total lipid from microorganisms found in the large intestine (Cho and Salton, 1966; Dowhan, 1997). Ileal digestibility values are better suited for use in predicting the digestibility of dietary fatty acids because fatty acid absorption occurs along the small intestine. The proximal jejunum is the main site of lipid absorption, and all fatty acids are nearly absorbed by the time digesta reaches the ileum (Pond et al., 1995; Yen, 2001). In the present study, ileal digestibility values were quite similar in magnitude and direction to fecal digestibility values, and significant interactions between DDGS and tallow ( $P < 0.04$ ) were observed for ileal C16:0, C18:0, C18:2, PUFA, and SFA digestibilities (Table 3.4).

A significant interaction was detected ( $P < 0.01$ ) between DDGS and tallow for C16:0 apparent ileal digestibility. When both DDGS and tallow are included in the diet, digestibility of C16:0 was lower compared to all other dietary treatments. This interaction of DDGS and tallow may explain why belly and backfat depots have a reduced concentration of C16:0 when pigs are fed a combination diet compared to CON (Pomeranke, 2012, unpublished). Main effects of DDGS ( $P < 0.01$ ) and tallow ( $P < 0.01$ ) were also detected for apparent ileal digestibility of C16:0. Adding 30% DDGS lowered C16:0 apparent ileal digestibility compared to diets not including DDGS. Furthermore, the addition of tallow also decreased the apparent ileal digestibility of C16:0 compared with diets not containing tallow. The results from the present study are in disagreement with previous research results where the addition of tallow increased C16:0 ileal digestibility compared to rapeseed oil (Ozimek et al., 1984) and sunflower oil (Duran-Montge et al., 2007). It is well known that saturated fatty acids are less digestible compared to unsaturated fatty acids (Jorgensen et al., 1993; Overland et al., 1994). The

reduction in digestibility of C16:0 may be related to the lipid structure because saturated fatty acids are more stable and less chemically reactive compared to unsaturated fatty acids (Food Fat and Oils, 2006). Furthermore, the reduction in C16:0 digestibility in DDGS diets may be due to fiber surrounding the dietary triglycerides impeding the digestion process and preventing lipase enzymes from accessing the lipid. Finally, an interaction ( $P < 0.01$ ) between DDGS and tallow was observed for the percentage of digestible C16:0 (Table 3.4). As the level of DDGS and tallow increased in the diets, the percentage of digestible C16:0 also increased ( $P < 0.01$ ). Diets containing 10% tallow (10T0D and 10T30D) had the greatest amount of C16:0 digested (1.83 and 1.89%, respectively) compared to all other diets, but these diets also contained the greatest concentration of C16:0 (2.24 and 2.76%, respectively). Furthermore, main effects of DDGS and tallow were detected. The addition of 30% DDGS resulted in an increase ( $P < 0.01$ ) in the amount of digestible C16:0. Likewise, as the amount of tallow in the diet increased ( $P < 0.01$ ) the amounts of digestible C16:0 also increased.

There was a DDGS and tallow interaction for C18:0 digestibility indicating that when 5 or 10% tallow was included in diets without DDGS, ileal digestibility of C18:0 increased compared CON, but when DDGS and tallow were both added to the diet, C18:0 digestibility decreased. However, unlike fecal digestibility, main effects of DDGS and tallow were not different ( $P > 0.05$ ) for apparent ileal digestibility of C18:0. In belly fat, C18:0 was reduced with the addition of DDGS compared to CON, but was not altered by dietary tallow inclusion (Pomeranke, 2012, unpublished). However, in backfat, DDGS did not alter C18:0 composition, but the addition of tallow lowered C18:0 concentration (Pomeranke, 2012, unpublished). Similar to C16:0, an interaction ( $P < 0.01$ ) between

DDGS and tallow was observed for the percentage of digestible C18:0. As the level of DDGS and tallow increased in the diets, the percentage of dietary C18:0 also increased. Diets containing 10% tallow (10T0D and 10T30D) had the greatest concentration (1.22 and 1.08%, respectively) of digestible C18:0 compared to all other diets. Furthermore, main effects of DDGS and tallow were detected. The addition of 30% DDGS tended to increase ( $P < 0.08$ ) the amounts of digestible C18:0 compared to diets not containing DDGS. Likewise, the addition of tallow in the diet increased ( $P < 0.01$ ) the amount of C18:0 digested compared to diets not containing tallow..

There tended ( $P < 0.09$ ) to be a significant interaction between DDGS and tallow for C18:1 apparent ileal digestibility, which be explained that by adding DDGS to the diet (0T30D, 5T30D, 10T30D; 74.8, 76.3, 79.3%, respectively), apparent ileal digestibility of C18:1 was lower than when tallow but no DDGS was included in the diet (5T0D and 10T0D; 78.6 and 85.4%, respectively). The addition of 30% DDGS lowered ( $P < 0.05$ ) C18:1 apparent ileal digestibility for 0T30D, 5T30D, 10T30D compared with CON, 5T0D, 10T3D. The type or level of dietary fiber may be responsible for interfering with fat digestion. Stein (2009) suggested the fermentation process in ethanol production may liberate oil and make fat slightly more digestible. Tallow inclusion increased ( $P < 0.02$ ) apparent ileal digestibility for 5T0D, 5T30D, 10T0D, 10T30D compared with CON and 0T30D, which agrees with results reported from Duran-Montge et al. (2007) where barley-based diets supplemented with tallow had greater ileal digestibility of C18:1 compared to the control diet. The tallow used in this study contained a relatively large proportion of C18:1 (43.9%). Due to the high concentration of C18:1 in tallow, and, thus, in the final diet (Table 3.4), the high dietary concentration of C18:1 may be another

reason why digestibility increased. Furthermore, the increased digestibility of diets containing tallow may relate to the increased concentration of C18:1 in belly fat and backfat when tallow is fed (Pomeranke, 2012 unpublished). However, the inclusion of 30% DDGS lowered C18:1 content in the backfat and tended to decrease it in belly fat (Pomeranke, 2012 unpublished; Xu et al., 2010b). Finally, an interaction ( $P < 0.01$ ) between DDGS and tallow was observed for the percentage of digestible C18:1 (Table 3.4). As the level of DDGS and tallow increased in the diets, the amount of digestible C18:1 also increased from 0.61 to 3.86% for CON and 10T30D, respectively. Furthermore, main effects of DDGS and tallow were detected. The addition of 30% DDGS resulted in an increase ( $P < 0.01$ ) in the amount of C18:1 digested, and the addition of tallow to the diet also increased ( $P < 0.01$ ) the amounts of digestible C18:1 indicating that the amount of C18:1 digested is a function of the amount of C18:1 found in the diet.

An interaction between DDGS and tallow was observed for apparent ileal digestibility of C18:2 ( $P < 0.04$ ). Digestibility was greatest for CON (76.55%) compared to all other diets, but was lowest for 5T0D (56.60%) and 10T0D (60.13%). Apparent ileal digestibility was reduced for 10T30D (56.6%) compared to CON and 0T30D (76.7, 66.2%, respectively). Although the DDGS used in this study contained 55.8% linoleic acid as a percentage of total fat, no main effects of DDGS addition were detected for C18:2 apparent ileal digestibility. No interactions between tallow and DDGS were observed for amount C18:2 digested. However, the dietary addition of DDGS resulted in a greater ( $P < 0.01$ ) amount of C18:2 digested compared to diets not containing DDGS, which is logical since DDGS contributed a high proportion of C18:2 to the diet.

Furthermore, the addition of 5 or 10% tallow tended to reduce ( $P < 0.07$ ) the percentage of C18:2 digested compared to when tallow was not present in the diet. Furthermore, DDGS addition has been shown to increase the amount of C18:2 in pork fat depots (Pomeranke, 2012, unpublished, Stein and Shurson, 2009). Therefore, the amount of digestible C18:2 is reflected in the increased in C18:2 in backfat and belly fat (Pomeranke, 2012, unpublished). The addition of dietary tallow ( $P < 0.01$ ) decreased C18:2 apparent ileal digestibility compared to diets not containing tallow, which agrees with results from previous research (Duran-Montge et al., 2007). The apparent ileal digestibility of C18:2 has been reported to range from 75% to 99% (Jorgensen et al., 1993; Jorgensen et al., 2000). In the present study, C18:2 digestibility ranged from 56.6 to 96.2%.

There tended ( $P < 0.07$ ) to be a significant interaction between DDGS and tallow for MUFA apparent ileal digestibility. When DDGS was not present in diets but 10% tallow was included, MUFA digestibility was greater compared with CON. When DDGS was included with supplemental tallow (5T30D, 10T30D), MUFA digestibility was similar to CON, 5T0D, 0T30D. Moreover, the addition of 30% DDGS tended ( $P < 0.06$ ) to lower MUFA apparent ileal digestibility in comparison with diets not including DDGS. Tallow addition increased MUFA apparent ileal digestibility ( $P < 0.01$ ) compared to diets not containing tallow. When DDGS was included in the diet, MUFA digestibility was greater ( $P < 0.01$ ) compared to when it was not present. Likewise, the inclusion of dietary tallow increased ( $P < 0.01$ ) the amount of MUFA digested.

An interaction ( $P < 0.01$ ) between DDGS and tallow was detected for apparent ileal digestibility of PUFA. Apparent digestibility of PUFA was greatest for CON at

77.82%, but was reduced to 65.9 and 57.4%, respectively, for 5T30D and 10T30D, which suggests a fiber and fat interaction with fiber possibly inhibiting digestive lipases from accessing the lipid. Moreover, the addition of tallow ( $P < 0.01$ ) caused a reduction in the apparent digestibility of PUFA compared with diets containing no tallow. The addition of DDGS to the diet increased ( $P < 0.01$ ) the amount of PUFA digested compared to diets not containing DDGS. Additionally, the inclusion of tallow resulted in increased ( $P < 0.01$ ) concentrations of PUFA digested compared to diets containing no tallow.

An interaction for SFA between DDGS and tallow was observed ( $P < 0.01$ ) where apparent ileal digestibility was lowest for 5T30D and 10T30D (68.2, 66.3%, respectively) compared to CON, 10T0D, and 0T30D (76.0, 80.0, and 79.9%, respectively). Diets containing 30% DDGS had lower ( $P < 0.01$ ) SFA apparent ileal digestibility compared to diets not containing DDGS. Furthermore, the addition of tallow caused a reduction ( $P < 0.01$ ) in SFA apparent ileal digestibility compared to diets not containing tallow. Finally, there was an interaction ( $P < 0.01$ ) between DDGS and tallow for the amount of digestible SFA. Diets containing 10% tallow, with or without DDGS (10T0D, 10T30D), contained the greatest amounts (3.32 and 3.41%, respectively) of digestible SFA compared to all other diets. Furthermore, the addition of DDGS increased ( $P < 0.01$ ) the concentration of digestible SFA compared to diets not containing DDGS. Likewise, the addition of tallow increased ( $P < 0.01$ ) the concentration of SFA digested compared to diets not containing tallow. Because tallow as an ingredient that contributes the majority of SFA to the diet, it is reasonable to expect that pigs fed diets containing tallow would digest more SFA since the diet contained a larger proportion of SFA than the other diets.

In the present experiment, many interactions between DDGS and tallow were

observed for fecal and ileal digestibility. The fiber component of DDGS may explain the lower fatty acid digestibility values when high concentrations of DDGS were fed, because Just (1982) showed that as crude fiber increased in the diet, apparent fat digestibility decreased. In the present experiment, crude fiber and NDF levels of the diet are presented in Table 3.4. Kil et al. (2010) indicated that extracted fat, such as corn oil, has a greater digestibility than intact fat from corn germ meal at the ileum and over the entire intestinal tract due to the physiochemical properties of the fat. Intact fat, as that from corn germ meal, is encased with fat cell membranes and is more resistant to formation of emulsions and enzymatic digestion than extracted fat (Adams and Jensen, 1984; Bach Knudsen et al., 1993; Kil et al., 2010). Similarly, Stein (2009) found the acid-hydrolyzed ether extract of corn oil is more digestible than intact forms of oils. However, of intact fat sources, high protein DDG and DDGS had greater digestibility of fat compared to high oil corn and corn germ (Stein, 2009). This suggests, that in DDGS, the fermentation process for ethanol production may have liberated some oil or made fat slightly more digestible in comparison with high oil corn and corn germ. However, intact fat sources, such as corn germ meal or DDGS, may have lower digestibility values because digestive enzymes may not have access to the substrate lipid because carbohydrate molecules, specifically fiber, may block access to the digestive lipase (Stein, 2009).

Ileal digestibility values for C18:1 and C18:2 are lower in this study compared to those reported by others (Ozimek et al., 1984; Jorgensen et al., 2000; Duran-Montge et al. 2007). The lower ileal digestibility values obtained in the present study may be due to the types of ingredients utilized in this experiment. Many of the previously published

ileal digestibility values, utilized ingredients other than corn such as barley (Duran-Montge et al., 2007), corn starch and soybean meal (Ozimek et al, 1984), wheat starch (Jorgensen et al, 2000), and cassava chips and soybean meal (Mitchothai et al., 2007) all of which have various levels of fiber, amino acids, and fat. Another possible explanation for reduced ileal digestibility values determined in the present study may be related to the use of different inert markers used to calculate digestibility. In the present study, acid insoluble ash was used as an inert marker; others have used dysprosium (Ozimek et al., 1984), chromic oxide (Overland et al, 1994; Jorgensen et al., 2000), and titanium dioxide (Duran-Montge et al., 2007). In a recent report by Kerr et al, (2010), no differences were detected between chromic oxide, iron oxide, or titanium dioxide on nutrient digestibility, but acid insoluble ash and dysprosium markers were not evaluated in this study.

In summary, these results suggest that C18:2 digestibility may not be related to deposition of C18:2 in pork fat depots because dietary DDGS inclusion did not alter C18:2 fecal or ileal digestibilities. However, the deposition of C18:2 is more closely related to the concentration of C18:2 in the diet rather than digestibility since pigs fed diets containing higher concentrations of C18:2 digested more C18:2 compared to diets containing low levels of C18:2.

Furthermore, combining 5 or 10% tallow with 30% DDGS in grower-finisher pig diets generally reduces the digestibility of nearly all fatty acids compared to CON and OT30D. However, the addition of DDGS and tallow generally increases the amounts of fatty acids digested, which is mainly a function of high concentration of fatty acids in the diet. Because the total amount of C18:2 is high in DDGS and DDGS containing diets, the deposition of C18:2 in adipose tissue is more closely related to the amount of C18:2 in the diet rather than its digestibility because pigs fed diets containing higher concentrations of C18:2,

digested more C18:2 compared to diets containing lower levels of C18:2. These are the first data reported in the literature that represent the digestibility of individual fatty acids in DDGS. However, to effectively manage dietary effects on pork fat quality, producers and nutritionists alike should consider implementing the use of iodine value product in formulation strategies. The iodine value product can estimate the iodine value in the diet based on the iodine value levels of specific ingredients containing fats or oils (Madsen et al, 1992). The iodine value product may be utilized to minimize the risk of exceeding desired pork fat quality standards.

**Table 3.1. Fatty acid profile, calculated iodine value and iodine value product of DDGS and tallow as a % of crude fat (as-fed basis)**

Item, %	DDGS	Tallow
Dry Matter	89.34	N/A <sup>1</sup>
Crude Fat	11.14	99.96
14:0	0.05	2.51
16:0	14.07	23.23
16:1	0.14	2.72
18:0	1.89	20.17
18:1	25.16	43.93
18:2	55.76	3.91
18:3	0.00	0.21
20:0	0.41	0.16
20:1	0.29	0.26
20:2	0.004	0.07
22:0	0.16	0.02
22:1	0.25	0.00
24:0	0.23	<0.001
Calculated IV <sup>2</sup>	119	48
Calculated IVP <sup>3</sup>	132	479

<sup>1</sup>N/A: Not Analyzed

<sup>2</sup>IV = 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, where the brackets indicate concentration (percentage) of fatty acid (AOCS, 1998).;

<sup>3</sup>IVP = Iodine Value Product = (IV of the dietary lipids) × (percentage dietary lipid) × 0.10 (Madsen et al., 1992).

**Table 3.2. Ingredient composition of diets, as-fed basis**

Tallow Ingredient, %	0% DDGS			30% DDGS		
	0% CON <sup>1</sup>	5% 5T0D <sup>1</sup>	10% 10T0D <sup>1</sup>	0% 0T30D <sup>1</sup>	5% 5T30D <sup>1</sup>	10% 10T30D <sup>1</sup>
Corn	70.65	64.73	58.81	54.58	48.67	42.72
Soybean Meal, 44%	25.62	26.39	27.17	10.99	11.76	12.59
DDGS	0	0	0	30.00	30.00	30.00
Beef Tallow	0	5.00	10.00	0	5.00	10.00
Limestone	0.75	0.75	0.74	0.81	0.80	0.80
Dicalcium Phosphate	1.36	1.37	1.37	1.52	1.53	1.53
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Celite	0.30	0.30	0.30	0.30	0.30	0.30
L-lysine	0.32	0.39	0.47	0.64	0.71	0.79
VTM premix <sup>2</sup>	0.50	0.50	0.50	0.50	0.50	0.50
L-threonine	0.11	0.17	0.23	0.18	0.23	0.26
L-tryptophan	0.03	0.03	0.03	0.12	0.13	0.13
DL-methionine	0.06	0.07	0.08	0.06	0.07	0.08
Total	100	100	100	100	100	100

<sup>1</sup>CON = corn-soybean meal control diet, 5T0D = CON and 5% tallow, 10T0D = CON and 10% tallow, 0T30D = CON plus 30% DDGS, 5T30D = CON plus 30% DDGS and 5% tallow, 10T30D = CON plus 30% DDGS and 10% tallow.

<sup>2</sup>Premix supplied the following per kg of diet: vitamin A, 11,000 IU; vitamin D<sub>3</sub>, 2,756 IU; vitamin E, 55 IU; vitamin B<sub>12</sub>, 55µg; riboflavin, 16,000 mg; pantothenic acid, 44.1 mg; niacin, 82.7 mg; Zn, 150 mg; Fe, 175 mg; Mn, 60 mg; Cu, 17.5 mg; I, 2 mg; and Se, 0.3 mg.

**Table 3.3. Nutrient composition of diets (as-fed basis)**

Nutrient	Tallow Level	0% DDGS			30% DDGS		
		0% CON <sup>1</sup>	5% 5T0D <sup>1</sup>	10% 10T0D <sup>1</sup>	0% 0T30D <sup>1</sup>	5% 5T30D <sup>1</sup>	10% 10T30D <sup>1</sup>
Dry Matter, %		86.86	87.21	87.91	88.53	89.15	89.71
Calculated ME, kcal/kg <sup>3</sup>		3845	3957	4170	3825	3885	4094
Crude Protein, %		19.09	17.79	17.08	19.07	17.70	18.02
Crude Fiber, %		2.10	1.96	1.71	3.04	3.13	3.10
NDF, %		9.19	8.00	7.33	14.41	14.36	14.36
Crude Fat, %		2.69	7.24	11.97	6.47	9.78	14.50
Linoleic Acid, %		1.69	1.70	1.71	2.78	2.88	3.09
Calculated SID Lys, %		1.09	1.16	1.23	1.09	1.16	1.23
Calculated SID Lys:ME (g/kcal ME)		3.28	3.28	3.28	3.30	3.30	3.29
Calculated Iodine Value Product <sup>2</sup>		39.00	55.00	69.20	68.70	81.20	102.90

<sup>1</sup>CON = corn-soybean meal control diet, 5T0D = CON and 5% tallow, 10T0D = CON and 10% tallow, 0T30D = CON plus 30% DDGS, 5T30D = CON plus 30% DDGS and 5% tallow, 10T30D = CON plus 30% DDGS and 10% tallow.

<sup>2</sup>IVP = Iodine Value Product = (IV of the dietary lipids) × (percentage dietary lipid) × 0.10 (Madsen et al., 1992).

<sup>3</sup>ME calculated based on ME=DE x 1.012-(0.0019 x % CP)) NRC (1998)

**Table 3.4. Analyzed fatty acid composition of the diet, fecal and apparent ileal digestibility as influenced by dietary level of DDGS and tallow, expressed as a % of total dietary fat, and percentage of apparent ileal digestible dietary fatty acids**

Tallow	0% DDGS			30% DDGS			PSE	DDGS	P-value	
	0%	5%	10%	0%	5%	10%			Tallow	DDGS× Tallow
	CON <sup>1</sup>	5T0D <sup>1</sup>	10T0D <sup>1</sup>	0T30D <sup>1</sup>	5T30D <sup>1</sup>	10T30D <sup>1</sup>				
<b>C16:0, %</b>										
FA content <sup>2</sup>	0.46	1.40	2.24	1.11	1.73	2.76				
Fecal Digestibility <sup>3</sup>	88.00 <sup>a</sup>	89.63 <sup>a</sup>	90.75 <sup>a</sup>	86.42 <sup>a</sup>	82.16 <sup>b</sup>	82.44 <sup>b</sup>	0.73	<0.01	<0.01	<0.01
Ileal Digestibility <sup>4</sup>	78.61 <sup>a</sup>	75.53 <sup>b,c</sup>	81.43 <sup>a,c</sup>	77.62 <sup>a,d</sup>	69.66 <sup>bd</sup>	68.43 <sup>bd</sup>	1.22	<0.01	<0.01	<0.01
Amount digested <sup>5</sup>	0.36 <sup>e</sup>	1.06 <sup>c</sup>	1.83 <sup>a</sup>	.86 <sup>d</sup>	1.20 <sup>b</sup>	1.89 <sup>a</sup>	0.02	<0.01	<0.01	<0.01
<b>C18:0, %</b>										
FA content <sup>2</sup>	0.09	0.85	1.58	0.43	0.95	1.76				
Fecal Digestibility <sup>3</sup>	-36.79 <sup>a</sup>	67.38 <sup>bd</sup>	78.43 <sup>bc</sup>	12.83 <sup>a,y</sup>	40.15 <sup>a</sup>	43.30 <sup>a,x</sup>	9.04	<0.01	<0.01	<0.01
Ileal Digestibility <sup>4</sup>	66.87 <sup>a</sup>	72.06 <sup>a,b</sup>	76.81 <sup>b,c</sup>	85.87	64.08	61.25	4.41	NS	NS	0.01
Amount digested <sup>5</sup>	0.06 <sup>d</sup>	0.61 <sup>b</sup>	1.22 <sup>a</sup>	0.37 <sup>c</sup>	0.61 <sup>b</sup>	1.08 <sup>a</sup>	0.04	<0.08	<0.01	<0.01
<b>C18:1, %</b>										
FA content <sup>2</sup>	0.82	2.54	4.05	2.00	3.12	5.03				
Fecal Digestibility <sup>3</sup>	95.14 <sup>a</sup>	97.47 <sup>b,c</sup>	98.03 <sup>b</sup>	97.65 <sup>b</sup>	96.12 <sup>a,c</sup>	97.48 <sup>b,c</sup>	0.41	NS	<0.01	<0.01
Ileal Digestibility <sup>4</sup>	74.41 <sup>a</sup>	78.57 <sup>c</sup>	85.44 <sup>d</sup>	74.80 <sup>b</sup>	76.30 <sup>b</sup>	76.65 <sup>b</sup>	2.05	<0.05	<0.02	<0.09
Amount digested <sup>5</sup>	0.61 <sup>a</sup>	1.99 <sup>b</sup>	3.46 <sup>c</sup>	1.49 <sup>d</sup>	2.38 <sup>e</sup>	3.86 <sup>f</sup>	0.07	<0.01	<0.01	<0.01

**C 18:2, %**

FA content <sup>2</sup>	1.69	1.70	1.71	2.78	2.88	3.09				
Fecal Digestibility <sup>3</sup>	98.15	96.90	97.14	97.61	96.62	97.13	0.59	NS	NS	NS
Ileal Digestibility <sup>4</sup>	76.55 <sup>a</sup>	56.60 <sup>b,c</sup>	60.13 <sup>b,c</sup>	65.93 <sup>a,c,x</sup>	64.64 <sup>a,c</sup>	50.98 <sup>b,c,y</sup>	3.77	NS	<0.01	<0.04
Amount digested <sup>5</sup>	1.29	0.96	1.03	1.84	1.86	1.57	0.10	<0.01	<0.07	NS

**MUFA, %**

FA content <sup>2</sup>	0.83	2.59	4.15	2.03	3.20	5.14				
Fecal Digestibility <sup>3</sup>	88.18 <sup>d</sup>	94.97 <sup>a</sup>	96.40 <sup>a</sup>	89.18 <sup>d</sup>	91.36 <sup>c</sup>	93.32 <sup>b</sup>	0.44	<0.01	<0.01	<0.01
Ileal Digestibility <sup>4</sup>	74.42 <sup>a</sup>	79.09 <sup>a,c</sup>	85.95 <sup>a,c</sup>	75.33 <sup>b,c</sup>	77.01 <sup>a</sup>	77.34 <sup>a</sup>	1.98	<0.06	<0.01	<0.07
Amount digested <sup>5</sup>	1.33	1.43	1.59	2.18	2.32	2.53	0.05	<0.01	<0.01	NS

**PUFA, %**

FA content <sup>2</sup>	1.79	1.81	1.85	2.89	3.02	3.27				
Fecal Digestibility <sup>3</sup>	97.86	96.64	96.88	97.16	96.06	96.57	0.60	NS	NS	NS
Ileal Digestibility <sup>4</sup>	77.17 <sup>a,x</sup>	57.94 <sup>a</sup>	61.86 <sup>a,c,y</sup>	66.23 <sup>a</sup>	65.20 <sup>a,c</sup>	52.16 <sup>b,c</sup>	3.63	NS	<0.01	0.03
Amount digested <sup>5</sup>	0.43	1.38	2.52	1.07	1.85	2.51	0.15	<0.01	<0.01	NS

**SFA, %**

FA content <sup>2</sup>	0.55	2.38	4.08	1.62	2.85	4.82				
Fecal Digestibility <sup>3</sup>	65.36 <sup>a</sup>	80.70 <sup>b</sup>	85.41 <sup>b</sup>	64.78 <sup>a</sup>	66.29 <sup>a</sup>	66.70 <sup>a</sup>	1.54	<0.01	<0.01	<0.01
Ileal Digestibility <sup>4</sup>	76.00 <sup>a</sup>	74.56 <sup>a,c</sup>	79.99 <sup>a</sup>	79.88 <sup>a</sup>	68.23 <sup>bc</sup>	66.29 <sup>b</sup>	1.77	<0.01	<0.01	<0.01
Amount digested <sup>5</sup>	0.63 <sup>e</sup>	1.93 <sup>c</sup>	3.32 <sup>a</sup>	1.62 <sup>d</sup>	2.18 <sup>b</sup>	3.41 <sup>a</sup>	0.06	<0.01	<0.01	<0.01

<sup>1</sup>CON = corn-soybean meal control diet, 5T0D = CON and 5% tallow, 10T0D = CON and 10% tallow, 0T30D = CON plus 30% DDGS, 5T30D = CON plus 30% DDGS and 5% tallow, 10T30D = CON plus 30% DDGS and 10% tallow.

<sup>2</sup> Analyzed fatty acid composition of diets, as-fed basis

<sup>3</sup> Fecal fatty acid digestibility as influenced by dietary level of DDGS and tallow, expressed as a % of total dietary fat

<sup>4</sup> Ileal fatty acid digestibility as influenced by dietary level of DDGS and tallow, expressed as a % of total dietary fat

<sup>5</sup> Percentage of apparent ileal digestible dietary fatty acids; calculated: ileal digestibility × fatty acid concentration in diet

<sup>a,b,c,d</sup> Within a row, means without a common superscript differ ( $P < 0.05$ )

<sup>x,y</sup> Within a row, means without a common superscript differ ( $0.05 < P < 0.10$ )

NS = Non-significant

## SUMMARY

In summary, feeding a combination diet of containing 5% tallow and 30% corn DDGS did not improve pork fat quality as we had hypothesized. In fact, in terms of pork fat quality, the combination of DDGS and tallow, exacerbated the negative effects of feeding DDGS on pork fat quality because iodine value in belly and backfat depots were higher compared with the control diet. Furthermore, the concentration of C18:2 was increased with the addition of 30% DDGS, but was not reduced with the addition of tallow. This finding, along with other individual fatty acid data, indicates that the dietary addition of tallow was ineffective in reducing the occurrence soft pork fat. However, feeding the combination diet resulted in no difference in growth performance compared to the control diet. In fact, no difference in ADG or G:F was observed when feeding 30% DDGS and 5% tallow compared to the control. However, the combination diet tended to reduce ADFI, which is the result of the increased caloric density of the diet due to the addition of tallow. In terms of carcass composition, feeding diets containing the combination of 30% DDGS and 5% tallow resulted in no change in HCW, carcass yield, backfat depth, or loin depth compared with pigs fed corn-soybean meal diets. However, pigs fed the combination diet were less lean compared to their contemporaries fed the corn-soybean meal control diet.

In the second experiment, ileal and fecal digestibility of fatty acids were investigated. Apparent ileal digestibility values of fatty acids are more meaningful for understanding fatty acid digestion and absorption compared to fecal digestibility because nearly all fatty acids are digested and absorbed by the time digesta reaches the distal ileum. Combining 5 or 10% tallow with 30% DDGS generally reduced the digestibility

of fatty acids compared to the control diet. Most importantly, these results suggest that C18:2 deposition in pork fat depots may not be necessarily related to the digestibility of C18:2 because dietary DDGS inclusion did not alter C18:2 fecal or ileal digestibility. Furthermore, because the total amount of C18:2 is high in DDGS and DDGS containing diets, the deposition of C18:2 in pig adipose tissue is more closely related to the amount of C18:2 in the diet rather than its digestibility since pigs fed diets containing higher concentrations of C18:2, digested more C18:2 compared to diets containing lower levels of C18:2. Overall, the interaction between fat and fiber needs to be further evaluated and better understood in monogastric animals.

Overall, producers should not feed 30% DDGS and 5% tallow for the entire growing-finishing period if they are concerned about pork fat quality. Instead, they should focus on alternative strategies such as formulating diets based on an iodine value product. Furthermore, other approaches for effectively managing the negative effects on pork fat quality from feeding DDGS include withdrawing DDGS from the diet prior to harvest or adding conjugated linoleic acid to the diet.

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