EFFECTS OF PELLETING GROWING-FINISHING DIETS WITH DISTILLERS DRIED GRAINS WITH SOLUBLES (DDGS) ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND COMMERCIAL BACON SLICING YIELDS OF BARROWS AND GILTS

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Animal Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2015

Urbana, Illinois

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ABSTRACT

Barrows and gilts (192, initial BW = 25.75 ± 2.29 kg) were allotted to two 24-pen blocks with 2 barrows and 2 gilts per pen. A 2 × 2 factorial arrangement of treatments in a randomized complete block design was used with two diet forms (meal or pellet) and two levels of distillers dried grains with solubles (**DDGS**, 0 or 30%) resulting in four treatment combinations. Pigs were weighed at the beginning of the experiment and again at the end of each of the 3 feeding phases (d 35, 70, 91). Pigs were slaughtered at the University of Illinois Meat Science Laboratory at the end of the 91 d feeding trial. Full gastrointestinal (**GI**) tract and GI tract component weights were recorded immediately following evisceration. Carcass characteristics and meat quality were determined after a 24 h chill. Carcasses were fabricated and the bellies were collected for manufacture into bacon. Belly dimensions and flop distance were measured. A fat sample from each belly was collected for fatty acid analysis. Bacon was manufactured at a commercial processor and then returned to the University of Illinois Meat Science Laboratory for further evaluation.

Overall ADG was increased ($P < 0.01$) by 3.2% when pelleted diets were fed. Overall ADFI of pigs fed 30% DDGS was 4.7% greater ($P < 0.01$) than pigs fed 0% DDGS in meal form diets. Overall ADFI of pellet-fed pigs did not differ ($P \geq 0.19$) between the 30% and 0% DDGS diets. Pigs fed 0% DDGS had 2.7% greater ($P = 0.02$) overall G:F than pigs fed 30% DDGS in meal form diets. There was no difference ($P = 0.42$) in overall G:F regardless of DDGS inclusion in pigs fed pelleted diets. Full GI tracts of pellet-fed pigs represented 0.33 percentage units less ($P = 0.03$) of the ending live weight than meal-fed pigs due to decreased ($P < 0.01$) gut fill. Inclusion of DDGS increased ($P = 0.03$) full GI tract weight, large intestine weight ($P < 0.01$), and gut fill ($P = 0.02$). Severity of parakeratosis of the pars oesophagae was greater ($P < 0.01$) in

stomachs of pellet-fed pigs than in meal-fed pigs, but the magnitude of the difference was likely not great enough to negatively affect drop value of stomachs. There was no effect of DDGS inclusion on overall ADG ($P = 0.46$) regardless of diet form. Pellet-fed pigs had 2.9% heavier HCW ($P = 0.01$), 10.4% thicker 10^{th} rib back fat ($P = 0.01$), and 1.8 percentage unit less estimated lean percentage ($P = 0.04$) than meal-fed pigs. Bellies from pellet-fed pigs were 5.3% heavier ($P < 0.01$) but, were not proportionally different ($P = 0.55$) from meal-fed pigs. There were no differences ($P \geq 0.11$) in belly dimensions between meal and pellet-fed pigs. Belly fat iodine value (**IV**) of pellet-fed pigs was 3.1 units greater ($P < 0.0001$) than meal-fed pigs. Pellet-fed pigs had heavier belly green weight and those differences persisted throughout processing. Despite pellet-fed pigs having a greater IV than meal fed pigs, there were no differences in commercial bacon slicing yields among treatment groups. Even so, bellies from pellet-fed pigs produced more total bacon slices ($P < 0.01$) than bellies from meal-fed pigs, but had 3.1% fewer ($P < 0.01$) slices/kg of sliced belly. Inclusion of DDGS resulted in a 0.32 cm decrease ($P < 0.0001$) in belly thickness, a 4.97 cm decrease ($P < 0.0001$) in flop distance, and a 2.8% decrease ($P = 0.04$) in green weight. Belly fat of DDGS-fed pigs had a 7.1 unit greater ($P < 0.0001$) IV than pigs fed 0% DDGS diet. There was no effect ($P \geq 0.41$) of DDGS on slicing yields.

In conclusion, feeding pelleted diets improved growth performance, decreased the weight of the gastrointestinal tract, and increased carcass weight and carcass fatness. The increased carcass weight and fatness was reflected in the fresh bellies; which were heavier and fatter than bellies from meal-fed pigs. But feeding pelleted diets increased belly fat IV. As expected feeding 30% DDGS resulted in bellies that were thinner, had decreased flop distance, and a greater IV than pigs fed 0% DDGS. Despite pelleting increasing belly fat IV 3.1 units compared with meal-fed pigs, there was no effect of diet form on commercial bacon slicing yields. Moreover, even

though bellies of 30% DDGS-fed pigs had a 7.1 unit greater IV than 0% DDGS-fed pigs, there was no difference in commercial bacon slicing yields. Overall, pig producers can take advantages in efficiency and rate of gain offered by pelleting growing-finishing diets while increasing saleable pounds of carcass and, bacon manufacturers can use bellies from pigs fed pelleted diets without concern of negatively affecting slicing yields.

ACKNOWLEDGEMENTS

First, I would like to thank those who have spent long hours in the lab, at the farms, and travelling across the country going to packing plants: peers and coworkers at the Meat Science Laboratory. Thank you so much helping me with this project and others, for lending expertise and knowledge where I was lacking, and for spending long mornings cutting carcasses and late nights studying for exams. As iron sharpens iron you have all improved me as a scientist and a person; and none of this would have been possible without your help. Thank you Emily Arkfeld, Ben Bohrer, Ben Peterson, Kyle Wilson, and Elizabeth Hogan for your help killing, fabricating and collecting data. I would especially like to thank Jessica Lowell for all of her help on weigh days and really stepping up for the completion of this project. I would be remiss if I did not extend a thank you to those from Dr. Stein's group who helped me both at the farms and in the lab so, thank you John Mathai, Neil Jaworski, Caroline González-Vega, Diego Navarro, and Oscar Rojas.

I would like to thank my advisers, Drs. Dustin Boler and Anna Dilger for providing me with the opportunity to further my education at the University of Illinois. Thank you for imparting upon me a piece of your knowledge, developing my skills as a scientist, the ability to think critically, and most of all, thank you for building in me the confidence that I can perform under pressure. Thanks are also owed to Dr. Hans Stein for serving on my committee, for overseeing the planning and initiation of the live phase of this experiment, and for allowing me the use of their lab space, equipment and expertise. The farm crew at the Swine Research Center as well as the staff at the Meat Science lab were also an integral part of the success of this project and they deserve much gratitude.

I would like to thank my father for inspiring my love of agriculture and spending time with me on the farm as a child. I would like to thank my mother for teaching me the importance of an active and creative mind as well as showing me every day what it meant to give it your all. Thank you both so much for all your unconditional love and support over the last 24 years.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

In the United States, 78.3% of all pork products consumed in the home are further processed (ham, bacon, sausage, etc.; Pork Check Off, 2009). Bacon alone represents 18.1% of all in home U.S. pork consumption (Pork Check Off, 2009). Because bacon represents such a large share of the market of pork products, producers, packers, and processors have had to direct more attention and resources into producing pigs that will yield bellies that will be suitable for the manufacture of bacon.

Historically, producers have selected pigs for increased lean growth. Although this has been beneficial in many markets, it can be detrimental to belly quality. Thus, pig producers have sought a middle ground, selecting for slightly fatter pigs. Now producers are challenged with balancing the demand for higher quality, fatter bellies for bacon manufacture with consumer demands for lean muscle cuts. Lean bellies are generally thinner than bellies with a greater percentage of fat, and thin bellies have reduced slicing yields and a lesser percentage of #1 slices (a #1 slice is one in which the secondary lean extends at least 50% of the length of the slice) than bellies that are average or thick (Person et al., 2005). In addition to having less fat, leaner pigs have a greater proportion of unsaturated fats which are softer and oilier than saturated fats, a trait that has often been linked to poor bacon slicing yields and slice quality (Shackelford et al., 1990).

Swine diets are processed in several ways; including grinding, pelleting, and extrusion. Of the processing technologies used, grinding is the most common and the least expensive. Pelleting and extrusion both require investment in specialized equipment and require more energy to process. Pelleted feed is more expensive to produce due to the capital investment in necessary equipment and energy. Pigs fed pelleted diets have greater average daily gain (Wondra

et al., 1995) and gain to feed ratios (Skoch et al. 1983; Wondra et al., 1995) than pigs fed the same diet in meal form. Whereas there are certainly benefits to feeding a pelleted diet, Nemechek et al. (2015) reported that iodine value of belly fat from pigs fed a pelleted diet was 2-3 units greater than in pigs fed a meal diet. Because greater belly fat IV has reduced the quality of bellies and it is believed that increased IV results in reduced commercial bacon slicing yields, it is possible that pigs fed pelleted diets will produce lower quality bellies and this may negatively affect commercial bacon slicing yield. To date, no study has evaluated the effect of feeding pelleted diets on commercial bacon processing characteristics and slicing yield.

CHAPTER 2: REVIEW OF LITERATURE

Feed processing technology

Grinding, pelleting, expanding, and extrusion are among the feed processing technologies available to improve feed handling characteristics and nutrient digestibility (Baird et al., 1973; Bengala-Freire et al., 1991; Wondra et al., 1995a,b, Hancock and Behnke, 2001; Zijlstra et al., 2009; Nemecheck et al., 2015), thus improving growth performance. The advantages of ground diets has been long recognized, when Frapp (1932) reported improved nutrient digestibility when pigs were fed ground sorghum diets compared with whole sorghum. Building from this knowledge, research began to focus on the effects of grinding ingredients to smaller particle sizes. Numerous experiments reported improved nutrient digestibility with decreased particle size, in many types of grains (Woodsman et al., 1932; Healy et al., 1985; Wondra et al., 1995a,b; Kim et al., Oryschak et al., 2002; Kim et al., 2005; Rojas, 2015). Wondra et al. (1995a) evaluated the cost, production efficiency, and the effects of nutrient digestibility of corn diets ground to 1000, 800, 600, and 400 µm and determined that the optimum particle size was approximately 600 µm. Although growth performance improves as particle size of diets is reduced, bridging of feed in bins and augers, as well as dustiness, become more problematic (Skoch et al., 1983). In addition to issues arising with feed handling traits, reducing particle size also increases the incidence and severity of gastric lesions in the stomach of pigs (Wondra et al., 1995a,b,c; Rojas, 2015). However, the increase in gastric lesions does not appear to negate the improved growth performance or nutrient digestibility offered by feeding finely ground diets. Feed processing technologies, such as pelleting, are one method for eliminating these issues (Wondra et al., 1995a). Additionally, in times when the costs of feed ingredients are especially great, it becomes even more important to maximize nutrient digestibility of diets. In such scenarios, producers can

consider the benefits of using other feed processing technologies, such as pelleting and extrusion. However, the cost of investment in processing equipment must be compared to the improvements in growth efficiency and rate of gain.

Of the available further processing technologies, pelleting is the second most common after grinding and mixing (Hancock and Behnke, 2001). Pelleting has repeatedly improved efficiency of gain (NCR-42 Committee on Swine Nutrition, 1969; Hanke et al., 1972; Baird et al., 1973; Wondra et al., 1995a,b; Nemechek et al., 2015). The effect of feeding pelleted diets has had inconsistent effects on rate of gain with some experiments reporting an increase in ADG due to pelleting (Baird, 1973; Wondra et al., 1995a,b; Myers et al., 2013; Nemechek et al., 2015). However, others reported no difference in rate of gain between feeding meal or pelleted diets (NCR-42 Committee on Swine Nutrition, 1969; Hanke et al., 1972; Skoch et al., 1983, Matthews et al., 2014). It has been suggested inconsistent results of pelleting diets may be due to inconsistent pellet manufacturing conditions and pellet quality among experiments (Myers et al., 2013). The improvement in efficiency of gain has been attributed to improved digestibility of starch (Bengala-Freire et al., 1991; Rojas, 2015), fat (Xing et al., 2004), dry matter (DM), nitrogen (N), and gross energy (GE) (Wondra et al., 1995a) in pelleted diets compared with meal diets. Recent experiments have reported that feeding pelleted diets increased belly fat iodine value by 2-3 units (Matthews et al., 2014; Nemechek et al., 2015).

Pelleting is a thermal processing technique. Pellets are conditioned with steam and can reach 82 – 88° C, however, it is believed that the temperature of the pelleting die itself can approach 150°C (Behnke, 2007). These temperatures allow for the agglomeration of the particles of the feedstuff into a pellet form, but excessive exposure to high temperatures can result in Maillard reaction (Gerrard, 2002). The Maillard reaction occurs when an amino group of an

amino acid and the carbonyl group of a reducing sugar; such as glucose, fructose, or xylose, react with one another (Nursten, 2005). The amino acids in the form of Maillard products are less digestible than in the form of peptides and proteins (Gonzales-Vega et al., 2011; Almeida et al., 2013). Additionally, heating and cooling during the pelleting process can convert amylopectin into retrograde starch or amylase-resistant starch (Sauber and Owens, 2001), which negatively effects the digestibility of metabolizable energy (De Schrijver, et al., 1999; Sauber and Owens, 2001). But, when the pelleting process is done correctly and heating and cooling steps are well controlled, the process improves digestibility of several nutrients.

Another common explanation for improvements in efficiency of gain has been that pelleting diets reduces the amount of feed wasted by pigs (Skoch et al., 1983; Hancock and Behnke, 2001). However, this hypothesis has proven difficult to evaluate because methods for determining the difference in feed wastage from feed intake has yet to be adequately developed. Moreover, improvements in efficiency in gain have often occurred without a concurrent decrease in feed intake, further implicating that improvements in feed efficiency are being driven by increased rate of gain and improved nutrient digestibility rather than a decrease in feed wastage. The majority of the research on pelleting swine diets has revolved around corn-soy diets with little work conducted investigating the effects of pelleting on diets containing fibrous co-products, such as distillers dried grains with solubles (DDGS).

Within cereal diets, numerous attributes related to pellet quality and their effects on growth performance have been investigated. Among the first pellet traits to be investigated was pellet diameter. Conventional wisdom dictated that larger pigs (i.e. growing-finishing pigs) preferred and, would perform better with, large diameter pellets, while weaning pigs would perform best with smaller pellets (Hancock and Behnke, 2001). Weaning pigs may in fact grow

faster with smaller pellets, at least in the first 2 weeks after weaning, but with no difference after 2 weeks (Lavorel et al., 1984). The effects of pellet diameter on growth performance of weaning and growing-finishing pigs was also investigated by Traylor et al. (1996). In their experiments, pellets were manufactured with diameters of 2, 4, 8, and 12 mm. Pellet size did not affect any growth performance traits in weaning pigs. However, in growing-finishing pigs, as pellet diameter was increased, rate of gain was increased and the authors reported the optimum pellet size for maximizing G:F was 4 mm. The conclusions of the studies on the effects of pellet diameter indicate that pellet diameters of 4 mm are adequate for both nursery and growing-finishing pigs.

The quality of pellets has also received much scrutiny. Pellet quality is defined as the ability of pellets to endure handling and transport without excessive breakage (Hancock and Behnke, 2001). An indication of poor pellet quality is the presence of fine particles (fines) among a pelleted ration. From a feed handling perspective, a benefit of pelleting is reduced dustiness of diets. This benefit is negated if pellet quality is poor and there is a high percentage (in excess of 30%; Myers et al., 2013) of fines in a pelleted diet. Although the percentage of fines does not appear to affect ADG, Stark et al. (1993) reported that increasing the percentage of fines in a pelleted diet from 20% - 60% reduced feed efficiency compared with pelleted diets with fines removed, negating any feed efficiency benefits gained by pelleting. It has been suggested that poor growth performance due to fines in pelleted diets may be ameliorated by using wet/dry feeders by improving palatability and reducing feed wastage (Myers et al., 2013).

Several steps can be taken to improve pellet quality. Grinding feed ingredients to smaller particle sizes may improve pellet durability. Decreasing particle size enhances the penetration of heat and moisture into the pre-pelleted meal (Hemmingsen et al., 2008) and increases the surface

area available for feed particles to bind together (Parsons et al., 2006). Steam conditioning may be used on diets before pelleting, and in fact, steam conditioners are often included with the purchase of pellet mills (Hancock and Behnke, 2001). Steam conditioning adds heat and moisture, in the form of steam, to diets before pelleting. The purpose is to soften the meal, improve protein binding, and gelatinization of starch in the diet, creating a more durable pellet. Typically, the ground diet is exposed to 75-85° C temperatures for only a few seconds. Long term conditioning is also practiced with similar temperatures, with exposure time of several minutes. When used in conjunction with steam conditioning, grinding feed ingredients to smaller particle sizes may improve pellet durability. Decreasing particle size enhances the penetration of heat and moisture into the pre-pelleted meal (Hemmingsen et al., 2008). Grinding feed to smaller particle sizes increases the surface area available for feed particles to bind together during pelleting, without or with steam conditioning (Parsons et al., 2006). Expansion of diets may also be performed prior to pelleting to improve pellet durability (Lundblad et al., 2009). Expansion is the high pressure steam cooking followed by extrusion of the feedstuff. Once the pressure heated feedstuff is exposed to the normal atmosphere the rapid reduction in pressure causes the steam to evacuate, rupturing the cellular structure of the plant material (Haenlein et al., 1962). Expanding improves pellet quality by improving the gelatinization of starch. Expanding is performed almost exclusively to improve pellet quality, as nutrient digestibility is largely not improved with expanding compared to unexpanded diets (Callan et al., 2007), although there is evidence that expanding does improve lysine digestibility compared with pelleting (Lundblad et al., 2012). Whereas there are some benefits to using expanding technology to improve pellet quality, in the U.S. the cost of equipment ($300,000-$500,000; Hancock and Behnke, 2001) as well as

maintenance needs of such equipment renders their use unfeasible to many producers in most circumstances.

Binding agents, such as lignosulfonates, sodium/calcium bentonites, hemicellulose extracts, and modified starch products may be used to improve pellet quality (Hancock and Behnke, 2001). Water alone, added to mash diets prior to pelleting, can also act as a binding agent (Moritz et al., 2001). And while binding agents do improve pellet quality and durability, there is little evidence to state that binding agents improve growth performance of pigs.

Stomach ulceration and keratinization

Pig stomachs consist of four distinct regions that differ in both appearance and structure (Yen, 2001). The esophageal region, or the pars oesophagea, is made of non-glandular tissue and is an extension of the esophagus into the stomach. Bordering the pars oesophagea is the cardiac region. The cardiac region accounts for approximately 1/3 of the luminal surface of the stomach and is pale gray in color. From the cardiac region, mucus, proteases and lipases are secreted. The fundic region of the stomach is a mottled brown-red color and accounts for another 1/3 of the luminal surface area. The fundic region lies between the cardiac region and the pyloric region. Three types of secretory cells exist in the fundic tissue; mucus neck cells, which secrete mucus and proteases, parietal (oxyntic) cells, which secrete HCl, and protease secreting chief cells. The pyloric region is last section of the stomach before transitioning into the entry of the small intestine and is pale in color. Like the fundic region, mucous neck cells and chief cells are present in the pyloric region, but not parietal cells.

Stomach ulcers and parakeratosis of the pars oesophagae of the stomach has been a recognized concern for the swine industry since Bullard (1951) first identified esophogastric ulcers as the cause of death of an adult boar. The majority of the work conducted on the

development of ulcers in pigs has been focused on the effects of different feedstuffs and particle size of diets. There are different types of ulcers that affect the different regions of the pigs stomach but, the esophageal region is the most at risk, especially when particle size is reduced (Mahan et al., 1966; Maxwell et al., 1970). This is because the other areas of the stomach have a protective mucus membrane, while the pars oesophagae region is relatively unprotected (Ohara et al., 1993). Feeding pelleted diets can also increase the incidence and severity of gastric ulcers (Gamble et al., 1967; Wondra et al., 1995a,b; Nielsen and Ingvartsen, 2000). Maxwell (1970) reported that reducing particle size of diets increased the fluidity of stomach contents and increased concentrations of pepsin. Nielsen and Ingvartsen (2001) hypothesized that reducing particle size or pelleting diets resulted in more fluid-like stomach contents, allowing for more mixing and that this allowed for digestive acids to be constantly in contact with the esophageal region. Development of gastric ulcer is considered a source of major economic losses for the U.S. swine industry (Friendship, 2003). De Jong et al. (2015) reported that pigs fed pelleted diets had more severe esophogastric ulceration and keratinization as well as having a greater number of pig removals on the farm compared with pigs fed a diet in meal form. While, acute bleeding ulcers, in which gastric juices are able to escape the stomach (10 on the 0-10 scale described by Nielsen and Ingvartsen, 2000) result in pig death, an increase in gastric lesions of the stomach, to a certain point, does not appear to negatively affect the performance of growing finishing pigs. The several months that growing-finishing pigs are on feed does not allow for the progression of gastric lesions to develop from parakeratosis to more severe ulcers, such as may be observed in sows fed over a longer period of time (Wondra et al., 1995c). Feed technologies that increase the severity of gastric lesions, such as reducing particle size and pelleting, also improve pig performance. Reducing particle size of diets increases the incidence and severity of

esophogastric keratinization and ulceration, but also improves nutrient digestibility and growth performance (Wondra et al., 1995a; Rojas, 2015). And the improvement in performance and nutrient digestibility appears to outweigh the costs associated with any negative affect ulceration may cause to growth.

In recent years, increased economic growth in Asia and in developing nations across the world has increased demand for animal protein, including variety meats (Vernooij, 2013). This has led to an increased value of pork variety meats, including stomachs. In 2001, the average price of a pig stomach was $58.63/cwt (Gralapp-Gonzalez, 2002). Since then the value of stomachs has consistently increased. By late July 2015 the price of stomachs destined for export had increased to $98.00/cwt with prices consistently above $70/cwt for the first quarter of 2015 (USDA, 2015). The development of esophogastric ulcers in the stomach potentially reduces the value of the stomach, constituting a loss in value of the drop credit of the carcass. Though the majority of considerations for ulcer development in pigs have focused on animal health and economic losses due to pig losses, economic losses at the packers end should also be considered.

Distiller's dried grains with solubles (DDGS)

Distiller's dried grains with solubles (DDGS) have become an important feedstuff for swine diets, particularly in times when cereal grain prices have been high in the U.S. Distillers dried grains with solubles are produced as a coproduct of the fermentation of cereal grains for ethanol production. Whereas corn is most commonly used to produce ethanol in North America, other cereal grains such as wheat and sorghum are used, and thus DDGS from these other grains are available (Stein and Shurson, 2009). In the production of ethanol from corn or other cereal grains, starch is fermented. This process leaves the unfermented portion, called wet distillers grains (WDG); including protein, lipid, fiber, and ash, as a co-product. Wet distillers grains are

typically used in ruminant diets; however, there is evidence that pigs fed 14-20% WDG may have improved ADG and G:F compared with pigs fed 20% DDGS in conjunction with a corn-soy diet (Meried, 2014). But due to their high moisture content, WDG rapidly spoil (7-10 days) and develop antinutritional compounds and thus are not commonly used in swine diets (Plain, 2006). At this point, the co-product may be dried to produce distiller's dried grains (DDG). Commonly, solubles will be added to the DDG to make DDGS (Shurson and Alghamdi, 2008). This product will typically contain 9 to 14% crude fat but, the crude fat can be centrifuged off to make a DDGS product with 5 to 8% crude fat (NRC, 2012). Because DDGS is a co-product of corn, wheat, or sorghum fermentation, the amino acid profile is reflective of the parent grain. Like corn, corn DDGS is limited in lysine and tryptophan (Stein and Shurson, 2009; Liu, 2011). Lysine in particular is variable in DDGS, as the drying process can cause lysine degradation due to overheating. Furthermore, the inclusion of solubles creates an environment more suitable for the Maillard reaction, further degrading lysine and having a deleterious effect on lysine digestibility. However, DDGS are an excellent source of amino acids and energy (in the form of crude fat), and are often a cost effective replacement in a corn-soy diet (NRC, 2012) and should be used as such.

For growing-finishing pigs, several experiments have reported DDGS can be added up to 30% in diets without affecting G:F (Xu et al., 2010a; Yoon et al., 2010; McDonnell et al., 2011) or ADG and ADFI (Yoon et al., 2010). There are, however, reports that feeding increasing levels of DDGS to growing-finishing pigs reduced ADG (Linneen et al., 2008) and G:F (Gaines et al., 2007; Asmus et al., 2014a). Although, less extensively researched, wheat DDGS reduces carcass yield similarly to corn DDGS (Thacker, 2006). Reports on the effect of feeding DDGS on carcass traits have been mixed but, feeding DDGS has reduced carcass yield in several studies

(Leick et al., 2010; Xu et al., 2010a; Dahlen et al., 2011; Graham et al., 2014). Though there have been several experiments reporting no effect of DDGS on carcass yield (Yoon et al., 2010; Kim et al., 2014; Tavárez et al., 2014). Inconsistency in results between experiments may be due to differing levels of DDGS fed and finishing weights, though it is generally accepted that up to 30% DDGS can be included in the diet with no negative effect on performance (Stein and Shurson, 2009; NRC, 2012). The decrease in carcass yield due to feeding fibrous feed stuffs, like DDGS, has been ascribed to an increase in the mass of the large intestine as well as an increase in gut fill due to the decreased digestibility of DM (Kass et al., 1980). Few differences in lean meat yield or fresh meat quality have been reported, however DDGS has consistently increased deposition of unsaturated fats (Benz et al., 2010; Leick et al., 2010; Asmus et al., 2014ab; Nemechek et al., 2015). The reason iodine value increases with the use of DDGS is that relatively large quantities of unsaturated fatty acids, especially of linoleic acid (C18:2), are present in corn and sorghum DDGS (Stein and Shurson, 2009). Inclusion of wheat DDGS in growing-finishing diets has an effect on fat quality similar to corn DDGS. For each 7.5% increase in wheat DDGS in the diet, polyunsaturated fatty acid concentration in belly fat increases by 11 to 15% and iodine value by 1.1 to 1.5 units (Beltranena et al., 2011). This increase in fat unsaturation results in the pigs yielding softer bellies, which have been assumed to be more difficult to slice (Cromwell et al., 2011). However, experiments investigating commercial slicing yields have drawn this assumption into question (Kyle et al., 2014). The negative effects of using DDGS on carcass yield and fat quality can be ameliorated by reducing the level, or completely withdrawing DDGS from the diet as little as 3-4 weeks before slaughter (Stein and Shurson, 2009). Reducing the level of DDGS from 30% to 0% three weeks before

slaughter increased carcass yield 1.3% and reduced jowl IV 3.7 units compared to pigs fed 30% DDGS throughout the growing-finishing period (Asmus et al., 2014b).

Fat Quality

Fat quality, as it pertains to meat, is characterized as the firmness, texture, and color of adipose tissue. In fresh pork bellies soft, oily, yellowish, unsaturated fats are considered to be low quality; whereas high quality fats are described as being white and firm (Wood et al., 1984). Pork fat quality is affected by numerous factors including sex, season, and diet. Iodine value of boars is greater than gilts which is greater than barrows (Kyle et al., 2014) and is a reflection of differences in leanness between the sexes. Limited data exists describing the effect of season on fat quality. But increasing housing temperature in finishing barns from 23.9°C to 32.2°C results in a small increase in IV, especially when pigs are densely populated in pens (0.93 m^2/pig vs. 0.66 m^2/pig; White et al., 2008). The results of the experiment indicate that changes in temperature with seasons may affect fat quality by inducing stress and suppressing growth, however data to confirm this are unreported. Of the factors, diet is the most effectual in manipulating fat quality. The fatty acid profile of fat depots in the pork carcass will reflect the fatty acid profile of the ingredients included in the diet. The inclusion of feedstuffs high in unsaturated fats results in increased concentrations of unsaturated fatty acids in pork fat depots (Miller et al., 1989; Shackelford et al., 1990; Specht-Overholt et al., 1997; Gatlin et al., 2002) while supplementing diets with saturated fats, such as tallow, will increase the saturated fatty acid content of the fat (Gatlin et al., 2002; Davis et al., 2015). Fat quality will also vary between depots within a carcass with jowl fat being more unsaturated than belly fat, and belly fat being more unsaturated than back fat (Asmus et al., 2014; Harris et al., 2015). In typical diets in which almost all energy is provided as starch (corn, wheat, barley), *de novo* synthesis accounts for the

majority of fat deposition. In pigs fed diets without supplemental sources of fat, *de novo* synthesis, the conversion of excess energy into stored fat, accounts for approximately 86% of all deposited non-essential fatty acids (Kloareg et al., 2007). Non-essential fatty acids are typically saturated and monounsaturated fats. But when fat is included in the diet, *de novo* synthesis is reduced and exogenous fatty acids from the diet begin to be deposited in adipose tissue (Azain, 2004) When the fat source comes in the form of a polyunsaturated oil, such as that in DDGS, fat of the pig will become unsaturated and softer. Fresh bellies exhibiting poor quality fat have been implicated in having poorer slicing yield than bellies with a greater concentration of saturated fats (Shackelford et al., 1990; Cromwell et al., 2011; Seman et al., 2013). Furthermore, issues may arise with the shelf life of products with poor fat quality due to hastened rates of oxidative rancidification (Wood et al., 2008; Leick et al., 2010).

There are a number of methods available to quantify fat quality in fresh pork bellies. These methods will fall into one of two categories: physical or chemical determination. The physical parameters that are most often used are belly flop distance and belly thickness. Belly flop distance is measured by placing the longitudinal midpoint of a skin-on belly on a stainless steel bar and measuring the distance between the skin edges of the anterior and posterior ends in centimeters. The measured distance is an objective indication of belly firmness (Thiel-Cooper et al., 2001). Other variations of the belly flop distance can be used. One such variation is the belly flex test where a skin-on belly is draped over a pipe with a diameter of 7.6 cm that is mounted perpendicular to a grid matrix. The intersection of the anterior and posterior edges with the *x*-axis is the lateral flex and the intersection of the edges of the belly with *y*-axis is referred to as the vertical axis (Rentfrow et al., 2003). In the flex test method, a greater vertical flex and lower lateral flex indicates a firm belly and a lower vertical flex and greater lateral flex indicates a soft

belly. A more subjective, but simpler method, is a subjective flop test and is more commonly used in commercial settings (Seman et al., 2013). In this method, the belly is folded and handled by a trained evaluator who assigns a flop value based on some previously calibrated scale. A method of evaluating belly firmness in recent years has been the use of a durometer. In this method skinned bellies are placed lean side down on a flat surface and the durometer is placed on the fat side of the belly. The durometer then measures the firmness of the tissue, with a greater value indicating firmer surface and lower values indicating a softer surface (Seman et al., 2013; Arkfeld et al., 2015). Seman et al. (2013) reported that durometer readings correlated better with commercial bacon slicing yield than predicted IV or subjective fat quality scores, but still only accounted for 13% of the variation in commercial bacon slicing yields. Belly thickness may also be used to assess belly fat quality. The thickness of the belly is measured by inserting the probe at 4 equidistant points along the dorsal half of the belly, beginning at the anterior end, and then repeating the procedure along the ventral half. The 8 measurements are then averaged and the resulting value is reported as the belly thickness. This method is effective because, generally thin bellies are also soft (Person et al., 2005).

Fat quality can also be quantified by measuring the Iodine Value (IV). Iodine value is an estimation of the unsaturation of fatty acids and is defined as the amount of iodine in grams that is consumed by 100 grams of a chemical substance. The procedure for measuring IV has historically been performed by treating the fatty acids with Hanus or Wijs solutions in glacial acetic acid. Potassium iodide is then added to the solution and the product of the reaction is iodine. The concentration of the unreacted iodine can then be quantified by titrating the solution with sodium thiosulfate.

Greater IVs indicate a greater amount of carbon-carbon double bonds as iodine interacts with the double bonds present in the structure of the fatty acid. For example, coconut oil is solid at room temperature and has an IV ranging from 7 to 10. Soybean oil, which is liquid at room temperature, has an IV range from 120 to 136. In a review of pork available in retail stores in 8 U.S. cities, Person et al. (2005) reported a minimum IV of 18.59 and a maximum of 103.12 of belly fat, with a mean IV of 67.51.

Iodine Value can also be determined by Near Infra-Red Spectroscopy (NIR) or may be defined based on concentrations of fatty acids. Both NIR and fatty acid concentration depends on measuring the proportion of specific fatty acids present in a sample. The lipids are removed from a sample of adipose tissue and subjected to gas chromatography (GC). Specific fatty acids are identified based up their retention time and area under the curve. This curve is compared to a standard with a known proportion of each fatty acid. The result is known as a fatty acid profile. Some of the most prevalent fatty acids in adipose tissue of pigs are as follows: oleic acid (18:1 n-9), palmitic acid (16:0), linoleic acid (18:2 *n*6), stearic acid (18:0), and myristic acid (14:0). The proportion of each fatty acid is then included in an equation. There are a number of different equations that may be used to calculate IV by the latter method.

One common regression equation is as follows (AOCS, 1998):

IV = C16:1(0.95) + C18:1(0.86) + C18:2(1.732) + C18:3(2.616) + C20:1(0.785) + C22:1(0.723)

Other equations are sometimes used that take into account other long-chain fatty acids in pork fat, especially when pigs are fed diets enriched with long chain fatty acid supplements. One such equation is as follows (Meadus et al., 2009):

IV = C16:1(0.95) + C18:1(0.86) + C18:2(1.732) + C18:3(2.616) + C20:1(0.795) + C20:2(1.57) + C20:3(2.38) + C20:4(3.19) + C20:5(4.01) + C22:4(2.93) + C22:5(3.68) + C22:6(4.64)

In both equations the coefficients paired with fatty acids with multiple double bonds (i.e., C18:2, C20:2) are greater than those fatty acids with only one double bond (i.e., C18:1). This is in reflection of the fact that with each additional double bond, the fatty acid becomes more unsaturated and has a lower melting point, thus is less solid at room temperature. When comparing IVs from different experiments it is important to note what equation was used and what impact that equation may have had on the reported IV. Despite IV being the predominant metric for predicting bacon sliceability, it correlates poorly with commercial bacon slicing yield ($r = -0.15$; $P < 0.05$; Kyle et al., 2014)

The quality of pork bellies may be determined by measuring the proximate composition of the belly. Because bellies with a greater amount of fat typically have a greater proportion of firm, saturated fats; measuring the proportion of fat in relation to lean and moisture in a sample will give an indication as to how firm the belly may be.

Fat percentage, moisture percentage, polyunsaturated fatty acid percentage, IV, green weight, flop distance, and belly thickness have been demonstrated to significantly correlate with commercial bacon slicing yield (Kyle et al., 2014). Although IV is often the standard for predicting slicing yields, it is not well correlated with slicing yields ($r = -0.15$; $P < 0.05$). Fat percentage ($r = 0.25$; $P < 0.001$), moisture ($r = -0.30$; $P < 0.001$), and belly thickness ($r = 0.27$; $P < 0.01$) were all better predictors of commercial bacon slicing yield.

While thickness, flop, proximate analysis, iodine value, and fatty acid profile are all measurements of fat quality they are not independent of one another. Each of the factors used to

evaluate fat quality in the belly are correlated to others. Bellies with a lower IV will generally be thicker and have greater flop distance. When evaluating the overall quality and predicting sliceability of a belly it is important to remember that while no individual measurement will tell the whole story, as some traits are influenced by other traits.

Bacon Processing

According to the Food Safety and Inspection Service of the USDA bacon is defined as the cured belly a swine carcass. Other parts of the carcass that are cured may also be called "bacon", but the name of the product must state from what part of the carcass it came from. It is believed that the process of curing meat was discovered when saltpeter was present as an impurity in salt used to preserve meat (Pearson and Gillett, 1996). In the U.S., the belly is the primal cut typically manufactured into bacon. The belly primal accounts for approximately 17 to 19% of the weight of the pork carcass from a finishing pig (Boler et al., 2011; Bohrer et al., 2013) and after the spareribs are removed, constitutes approximately 15% of the carcass weight (Boler et al., 2014). The weight of the belly as a percentage of carcass weight is not static throughout physiological development. As pigs mature the proportions of muscle, fat and bone change resulting in differences in weights of primal cuts in relation to carcass weight. In Piétrain pigs, the proportion of the carcass weight made of the belly increased from 11.2% in 20 kg pigs to 15.1% at 90 kg, but decreased to 13.9% at 120 kg (Landgraf et al., 2006). The reason for the decrease in belly weight in relation to carcass weight after pigs exceeded 90 kg was that the tissues of the belly primal, particularly of the fat, is earlier maturing than other tissues such as the loin and back fat (Landgraf et al., 2006). Whereas the bellies proportion of the carcass peaked at 90 kg, the proportion of the loin peaked at 120 kg and the proportion of back fat was greatest at 140 kg. Although, this relationship is generally true, there is variation among breeds. Nieto et al.

(2013) reported that belly weight as a percentage of carcass weight of slow growing, Iberian pigs increases from 12.4% in 10-25 kg pigs to 19.9% in 100-150 kg pigs, whereas the proportional weight of bellies from Piétrain pigs peaked at a lighter weight. The qualities of the belly are also affected by developmental stage and sex of the pig. Thickness of the belly, often a reflection of belly fatness and fat quality (both of which are generally increased with heavier pigs) affect processing yields (Kyle et al., 2014) and consumer acceptance of bacon (Person et al., 2005). The sex of the pig may also affect belly quality and processing characteristics. Bellies of gilts are generally lighter, thinner, have a greater IV than barrows but do not differ in commercial bacon slicing yield (Clark et al., 2014; Kyle et al., 2014). But fresh belly characteristics and slicing yields of barrows and gilts are both superior to bellies from intact males (Kyle et al., 2014).

Skinless bellies are typically injected with a cure solution containing water, salt, sodium or potassium nitrite, sugar, a cure adjunct, phosphate, and any number of spices and flavorings (Pearson and Gillett, 1996). Bellies are then thermally processed and often times smoked. Natural smoke flavoring may also be incorporated into the cure solution. In the U.S., the cooked yield of bacon is regulated as part of the standard of identity: According to U.S. regulations; "The weight of cured pork bellies ready for slicing and labeling as 'Bacon' shall not exceed the weight of the fresh uncured pork bellies" (9 CFR 319.107 – Bacon; USDA FSIS). To meet standards of identity requirements, the cooked bellies must weigh no more than the green bellies prior to injection with the cure solution. Next, the bellies are frozen and then tempered to approximately the freezing point of meat (~ - 2.2°C). After tempering, the cooked bellies are pressed and trimmed square. The squared and trimmed belly is then sliced. Incomplete slices and portions from the anterior and posterior ends of the belly sorted as "ends and pieces". Reports of commercial bacon slicing yields from industry are extremely limited due to their proprietary

nature. However, based on the available reports from experiments conducted in commercial bacon manufacturing plants slicing yields can range from 84 to 91% when calculated from cooked weight and 87 to 96% when calculated from green weight (Kyle et al., 2014; Tavárez et al., 2014).

The primary source of return from the manufacturing of the pork belly primal comes from the intact center slices. Pump uptake, cooked yield, chilled yield, and sliced yield are often measured when evaluating bacon processing. However, because cooking yields are fixed by USDA-FSIS regulation, the point in the process where the packer can impact yields the most is at slicing. Several factors may influence slicing yields including belly thickness (Person et al., 2005), temperature of the belly during slicing (James and James, 1987; Brown et al., 2003), belly storage conditions (Robles et al., 2004), and concentration of polyunsaturated fat (Shackelford et al., 1990). A greater proportion of unsaturated fatty acids, particularly polyunsaturated fats, will increase IV of fat. Greater IV has long been implicated as being deleterious to commercial bacon slicing yields (Shackelford et al., 1990; Person et al., 2005; Leick et al., 2010). But results of studies evaluating commercial bacon slicing yields have been inconsistent. Tavárez et al. (2014) reported that despite pigs that were fed 30% DDGS having a 7.5 unit greater IV than pigs fed no DDGS, there was no difference in commercial bacon slicing yields. However, Kyle et al. (2014) reported that physically castrated barrows had a 3.03 lesser belly fat IV and a 3.8% greater commercial bacon slicing yield than intact boars that were not fed ractopamine HCl.

The temperature at which the bacon is sliced also plays a role in determining slicing yield. The optimum temperature to slice bellies using as high speed slicer is dependent upon the salt concentration of the bacon and as salt concentration increases, the temperature at which slicing yield is maximized decreases. Brown et al. (2003) reported that the slicing yields were

maximized at approximately -5.5°C for bacon with 2.03% salt, -7°C for bacon with 3.36% salt, and at < -11°C for bacon with 5.69% salt. The storage conditions of bellies before processing also impacts slicing yield as well as slice quality. Bellies that go through a freeze-thaw cycle before curing have 1.74% lower slicing yield and have more severe shattering in center slices than bellies that were cured fresh (Robles, 2004).

Predicting Commercial Bacon Slicing Yield

There is evidence that traits traditionally relied upon to evaluate belly quality may not be good predictors of commercial bacon slicing yields. To quantify the association of any of the aforementioned fresh belly traits with slicing yields is achieved by use of Pearson correlation coefficients, annotated as "r". Correlation coefficients are bound between -1 and 1; that is an r = -1 denotes a negative association between two traits, and an r = 1 denotes a positive association between two traits (Tavárez, 2014). An example of a positive correlation would be when the level of trait *A* increases, the level of trait *B* increases. To date only one experiment has reported correlations of fresh belly traits and commercial bacon slicing yields (Kyle et al., 2014). The results of this experiment demonstrated that belly fat IV was poorly correlated (r = - 0.15; $P < 0.05$) with commercial bacon slicing yield and fat (r = 0.25; $P < 0.001$), moisture (r = - 0.30; $P < 0.001$), and belly thickness (r = 0.27; $P < 0.01$) were better correlated with commercial bacon slicing yield calculated from green weight. The authors also determined that total SFA concentration, Total MUFA concentration, Total PUFA concentration, UFA: SFA, and IV were all highly collinear as determined by using a variance inflation factor (VIF) statistic. Variance inflation factors are used to determine how much the variances of the estimated regression coefficients are inflated as compared to when the predictor variables that are not collinear. Collinearity exists when independent predictor variables are correlated among themselves

(Kutner et al., 2004). In this case, the existence of multicollinearity between fatty acid variables is not surprising. Each of the classes of fatty acids were calculated as a proportion of total fatty acids, thus as PUFA concentration increased the concentration of SFA, MUFA, or both decreased proportionally. A stepwise regression model was also calculated to predict commercial slicing yields calculated from green weight (Kyle et al., 2014):

Slicing yield = 77.7998 + 0.1273(flop distance) + 2.4433 (avg. belly thickness) + 1.4374(green weight)

This regression equation only accounted for 36% of the variation in commercial bacon slicing yield. This indicates that factors other than fresh belly characteristics may play a more prominent role in determining commercial bacon slicing yields. It is likely that processing conditions and techniques, such as bacon temperature at slicing (James and James, 1987; Brown et al., 2003) and storage conditions (Robles, 2004) play as an important a role as the quality of the raw material in predicting commercial bacon slicing yields.

Conclusions

Pelleting diets has repeatedly been demonstrated to improve growth performance of pigs. While the effects of pelleting on live animal performance have been thoroughly investigated, less data has been collected regarding the effects of pelleting on pork carcass traits and meat quality. The effects of DDGS on growing-finishing pig performance, carcass traits, and fat quality are well documented. But there is limited data on the effects of pelleting diets containing DDGS. Iodine value has long been the standard metric for predicting commercial bacon slicing yields. But, the role of iodine value as a good predictor of commercial bacon slicing yield has been drawn into question in recent years, and it is not known if the increase in iodine value caused by pelleting diets will be severe enough to negatively affect commercial bacon slicing yields.

Therefore, more research is necessary to fully understand the effects of pelleting, as well as any interactive effects with DDGS, on carcass characteristics, belly fat quality, and ultimately, commercial bacon slicing yields of growing-finishing pigs.

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CHAPTER 3: EFFECTS OF PELLETING GROWING-FINISHING DIETS AND DISTILLERS DRIED GRAINS WITH SOLUBLES ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND GASTROINTESTINAL WEIGHT OF BARROWS AND GILTS

ABSTRACT:

Barrows and gilts (192, initial BW = 25.75 ± 2.29 kg) were allotted to two 24-pen blocks with 2 barrows and 2 gilts per pen. A 2 × 2 factorial in a randomized complete block design was used with 2 diet forms (meal or pellet) and 2 levels of distillers dried grains with solubles (**DDGS**, 0 or 30%) resulting in 4 treatment combinations. Pigs were weighed at the beginning of the experiment and again at the end of each of the 3 feeding phases (d 35, 70, 91). Pigs were slaughtered at the University of Illinois Meat Science Laboratory at the end of the 91 d feeding trial. Full gastrointestinal (**GI**) tract and GI tract component weights were recorded immediately following evisceration. Carcass characteristics and meat quality were determined after a 24 h chill. Overall ADG was increased ($P < 0.01$) by 3.2% when pelleted diets were fed. Overall ADFI of pigs fed 30% DDGS was 4.7% greater ($P < 0.01$) than pigs fed 0% DDGS in meal form diets. Overall ADFI of pigs fed pelleted diets did not differ ($P \geq 0.19$) between the 30% and 0% DDGS diets. Pigs fed 0% DDGS had 2.7% greater ($P = 0.02$) overall G:F than pigs fed 30% DDGS in meal form. There was no difference ($P = 0.42$) in overall G:F regardless of DDGS inclusion in pellet form diets. There was no effect of DDGS inclusion on overall ADG ($P = 0.46$) regardless of diet form. Pigs fed pelleted diets had 2.9% heavier HCW ($P = 0.01$), 10.4% thicker 10^{th} rib back fat ($P = 0.01$), and 1.8 percentage unit less estimated lean percentage ($P = 0.04$) than meal-fed pigs. Full GI tracts of pigs fed pelleted diets represented 0.33 percentage units less ($P = 0.03$) of the ending live weight than meal-fed pigs due to decreased ($P < 0.01$) gut fill.

Inclusion of DDGS increased ($P = 0.03$) full GI tract weight, large intestine weight ($P < 0.01$), and gut fill ($P = 0.02$). Severity of parakeratosis of the pars oesophagae was greater ($P < 0.01$) in pigs fed pelleted diets than meal-fed pigs, but the magnitude of the difference was likely not great enough to negatively affect drop value of stomachs. Feeding pelleted diets improved growth performance, increased carcass weight and fatness without causing the development of gastric lesions that would likely reduce stomach the value of the stomach to packers.

INTRODUCTION

Pelleting swine diets is a technology used by the feed milling industry where a meal diet is subjected to heat and (or) moisture, then pressed through a die to agglomerate smaller particles into a larger composite (Hancock and Behnke, 2001). By pelleting, feed handling issues, such as flowability and bridging of finely ground diets in bulk bins and delivery systems, are ameliorated (Hancock and Behnke, 2001). Pelleting also reduces segregation of feedstuffs by pigs, increases bulk density, and reduces dustiness of the diet. Feeding pelleted diets improved nutrient digestibility(Wondra et al., 1995a; Rojas, 2015), feed efficiency (Wondra et al., 1995a; Nemechek et al., 2015), and in some experiments, increased rate of gain (Wondra et al., 1995a,b; Myers et al., 2013; Nemechek et al., 2015). Several experiments have reported no effect of diet form on any carcass characteristics (Wondra et al., 1995a,b; Myers et al., 2013; Nemechek et al., 2015). However, increased carcass yield (Fry et al., 2012), BF, and belly fat (Matthews et al., 2014) of pigs fed pelleted diets have been reported. Previously reported carcass characteristics of pigs have been conducted using loin and fat depth probe techniques, and the inconsistency of the results indicates the need for more in-depth investigation of the effect of pelleted diets on carcass traits. Additionally, beyond differences in carcass fatness, the role of gut fill differences in carcass yield between meal and pellet-fed pigs has not been investigated. Furthermore, pigs fed

pelleted diets had a greater instance and severity of esophagastric ulcers and parakeratosis (Gamble et al., 1967; Wondra et al., 1995a), but the effects of pelleting corn-soy diets and diets with 30% DDGS on gastrointestinal (**GI**) tract organ weights are unreported. The value of pork variety meats, such as stomachs, has increased in recent years due to increased demand from developing countries (Vernooij, 2013). The development of gastric lesions in pork stomachs could potentially reduce the value of pork stomachs, thus reducing the profitability of the non-carcass components (drop value) to packers. Therefore, the objectives of this experiment were to determine the effects of feeding pelleted diets on carcass characteristics, and gastrointestinal weights of growing-finishing pigs in order to explain previously reported differences in carcass yield.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for this experiment.

Experimental design and dietary treatments

A total of 192 crossbred barrows and gilts, with an initial BW of 25.75 ± 2.29 kg, were used in a 2 × 2 factorial design experiment in a randomized complete block design. Barrows and gilts were the offspring of G-performer boars mated to Fertilis-25 females (Genetiporc, Alexandria, MN). Pigs were placed in 2 equal blocks based on age. Each block consisted of 6 replications per treatment (12 total replications per treatment). Each replication included 4 pens with each pen housing 2 barrows and 2 gilts for a total of 24 pens per block (48 pens total). Pigs were allocated to pens at 10 wks of age based on initial BW such that pens were replicated by weight within each block. Pens of pigs within block were randomly allotted one of four dietary

treatments; 1.) meal form with 0% DDGS, 2.) meal form with 30% DDGS, 3.) pelleted form with 0% DDGS, or 4.) pelleted form with 30% DDGS.

Pigs were housed in a mechanically-ventilated building with partially slatted concrete floors for the entire feeding period. Pen dimensions were 2.59 × 1.83 m, which provided 1.18 m^2/pig. Each pen had a single-space dry box feeder mounted on the front gate and a nipple drinker. The thermostat was set at 18.4° C for the entire feeding period and ambient temperature was maintained using thermostatically controlled heaters and fan ventilation. A 3-phase, 91 d feeding program (Tables 3.1 to 3.4) was used with grower diets fed from d 0 to 35, early finisher diets fed from d 36 to 70, and late finisher diets fed from d 71 to 91. All diets were formulated to meet current estimates for nutrient requirements for growing-finishing pigs (NRC, 2012). All diets were formulated based on values for the standardized total tract digestibility of P, standardized ileal digestibility of AA, and NE (Table 3.1). Pigs were weighed at the beginning of the feeding period (d 0) and again at the end of each of the 3 feeding phases (d 35, 70, 91). Daily feed allotments were recorded, and data were summarized to calculate ADG, ADFI, and G:F for each pen for each phase of the feeding period. Samples of pelleted diets, both before and after pelleting, and meal diets were collected from each batch within each phase for chemical and physical analysis. The heaviest barrow and gilt from each pen were removed for slaughter on d 91. The remaining pigs remained on the experimental diets and were slaughtered two days later but ADG, ADFI, and G:F were not recorded during this time. Gastrointestinal tract organ weights were determined using the heaviest barrow and gilt from each pen. Carcass characteristics and fresh loin quality were evaluated on each carcass.

Slaughter Procedures and Evisceration

The day before slaughter, pigs were transported to the University of Illinois Meat Science Laboratory (Urbana, IL) and held for approximately 16 h in lairage. Pigs were provided ad libitum access to water and had no access to feed during this time. Pigs were weighed at the abattoir immediately before being slaughtered under the supervision of the Food Safety and Inspection Service of the United States Department of Agriculture. Pigs were immobilized using the head-to-heart electrical stunning technique followed by exsanguination. Full gastrointestinal (**GI**) tract and GI tract component weights were recorded immediately following evisceration according to the procedure described by Boler et al. (2014). Initially the full, intact GI tract was weighed. The large intestine was then separated from the small intestine at the ileocecal junction. The small intestine was separated from the stomach between the pylorus of the stomach and the duodenum of the small intestine. The stomach was removed from the esophagus where the esophagus empties into the cardiac of the stomach. Each section of the GI tract was rinsed with water to remove all digestive and fecal material. Mesenteric tissue surrounding the GI tract was removed and weighed separately. Gut fill was calculated as the difference between the full GI tract and the cleaned, separated components. The weight of the GI tract was calculated as the absolute weight and also as a percentage of ending live weight.

Stomachs were identified using tags corresponding to pig identification. The stomachs were placed in a cardboard box with a liner, and frozen at - 20° C following weighing and were thawed at a later date for evaluation of ulceration and keratinization.

Stomach Morphology Evaluation

Stomachs were allowed to thaw at 4° C for 72 h prior to evaluation. Stomachs were then cut open such that the pars oesophagae remained intact. Evaluation of ulceration and

parakeratosis in the pars oesophagae region of the stomach was conducted by 3 trained panelists using reference images according to the protocol described by Nielsen and Ingvartsen (2000). Stomachs were scored as follows: 0 – Normal, 1 – Minor parakeratosis, 2 – Medium parakeratosis, 3 – Severe parakeratosis, 4 – Minor gastric lesion or scar, 5 Medium gastric lesion or scar, 6 – Severe gastric lesion or scar and/or crater formation surrounding the entire oesophageal entrance into stomach, 7 – Reduction of pars oesophagae to 3 × 6 cm due to scarring and/or contraction of the oesophageal opening to a diameter of 10 mm, 8 – Reduction of pars oesophagae to 2 × 4 cm due to scarring and/or contraction of oesphogeal opening to a diameter of 7 mm, 9 – Reduction of pars oesophagae to 1 × 2 cm due to scarring and/or contraction of the oesphogeal opening to a diameter of 4 mm with a callused esophagus, and 10 – a.) Pig died from a bleeding ulcer, b.) oesophageal opening reduced to 2 mm and sever callusing of the esophagus. The scores of the three panelists were averaged and recorded as ulcer score.

Carcass Measurements

Hot carcass weight was collected immediately after the carcasses passed postmortem inspection. After chilling (24 h), the left side of each carcass was cut at the location of the 10^{th} rib. Back fat was measured perpendicular to the skin at 3/4 the length of the loin eye at the 10^{th} rib. Loin eye area (**LEA**) was measured by first tracing the *longissimus* muscle (**LM**) on double matted acetate paper. Then, loin muscle outlines were traced in duplicate using a digitizer pad (Intuos Pro Digitizer Tablet and stylus, Wacom Technology Corporation, Vancouver, WA, USA), and the area was measured using the magic wand tool of Adobe Photoshop CS6 (Adobe Systems Inc, San Jose, CA, USA). The average of the 2 measurements was reported as LEA. Estimated lean was determined using the following equation (Burson and Berg, 2001): estimated

lean, % = [8.588 + (0.465 × HCW, lbs) – (21.896 × BF, in) + 3.005 × LEA, in^2) / HCW, kg × 100] / HCW, kg.

Fresh Loin Quality

Subjective color, objective color, proximate composition, ultimate pH, drip loss, cook loss and shear force evaluations and analyses were conducted by trained University of Illinois personnel. Ultimate pH, objective color, subjective color, marbling and firmness scores were collected from the cut surface of the LM of left side of each carcass 30 minutes after they were cut at the location of the 10^{th} rib. Ultimate pH was measured 24 h post mortem using a handheld MPI pH meter fitted with a glass electrode (MPI pH-Meter, Topeka, KS, USA; 2-point calibration; pH 4 and pH 7). Objective CIE L* (lightness), a* (redness), and b* (yellowness; CIE 1978) were collected with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) utilizing a D_{65} light source and a 0° observer with an aperture size of 8 mm. Subjective color and marbling scores (NPPC, 1999), and firmness scores (NPPC, 1991) were conducted by a single observer according to the standards created by the National Pork Producers Council. A 7 cm section of the loin was removed from the carcass posterior to the cut at the 10^{th} rib. From this section, a 2.54 cm chop was cut from the anterior end for analysis of proximate composition, a 1.27 cm section was cut for determination of drip loss, and a 2.54 cm chop was collected for use in Warner-Bratzler shear force evaluation. The drip loss method as described by Boler et al. (2011) was used to determine water holding capacity and results were reported as a percentage of weight loss. Loin section samples were prepared for proximate composition analysis by removing subcutaneous fat and homogenizing in a food processor. Moisture and lipid content were quantified using the chloroform-methanol solvent as described by Novakofski et al. (1989).

Warner-Bratzler Shear Force

The 2.54 cm thick chops that were removed from the section of the left LM of each carcass were vacuum-packaged and stored at 4°C for 14 days postmortem. At the conclusion of the 14 d aging period, chops were frozen and stored at - 40° C until analysis could be completed. Chops were removed from the freezer and allowed to thaw at 4°C for approximately 18 h before analysis. Chops were trimmed of excess fat and cooked on a Farberware Open Hearth grill (model 455N, Walter Kidde, Bronx, NY, USA). Chops were cooked on one side to an internal temperature of 35°C, flipped, and then cooked until they reached an internal temperature of 70°C. Internal temperature was monitored utilizing copper-constantan thermocouples (Type T, Omega Engineering, Stamford, CT, USA) connected to a digital scanning thermometer (model 92000-00, Barnant Co., Barrington, IL, USA). Chops were allowed to cool to 25°C and 4 cores, each measuring 1.25 cm in diameter, were removed parallel to the orientation of the muscle fibers. Cores were sheared using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY, USA / Stable Microsystems, Godalming, UK) with a blade speed of 3.3 mm/s and a load cell capacity of 100 kg. A single shear force was determined for each core. Shear force was reported as the average of the 4 cores. Cook loss was determined by weighing chops used for shear force before cooking and again after cooking (Boler et al., 2011). Cook loss was reported as a percentage of weight lost during cooking.

Diet Analyses

Diets were analyzed for GE using bomb calorimetry (Model 6300 Parr Instruments, Moline, IL), DM (method 930.15; AOC Int., 2007), CP by combustion (method 999.03; AOAC Int., 2007) on a Rapid N cube (Elementar Americas Inc, Mt Laurel, NJ) and ash (method 942.05; AOAC Int., 2007). Acid hydrolyzed ether extract (**AEE**) was determined by acid hydrolysis

utilizing 3*N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (method 2003.06, AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN, USA). Diets were also analyzed for AA (Method 982.20 E [a, b, c]; AOAC Int., 2007), ADF (method 973.18; AOAC Int., 2007), NDF (Holst, 1973), and P and Ca were analyzed by inductively coupled plasma spectroscopy (method 975.03; AOAC Int., 2007) after wet ash sample preparation. Mean particle size and distribution was determined as described by Rojas-Martinez (2015). Bulk density was determined as described by Cromwell et al. (2000). Angle of repose was determined using the protocol described by Appel (1994).

Statistical Analyses

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC, USA) as a 2 × 2 factorial arrangement of treatments in a randomized complete block design with 6 replicate pens per block and 12 pens per treatment. Pen (N=48) served as experimental unit for all dependent variables. Fixed effects were diet form (meal or pellet), DDGS inclusion (0% or 30%), and the interaction between diet form and DDGS inclusion. Block and replication nested within block were random variables. Assumptions of ANOVA were tested with Levene's test and Brown-Forsythe for homogeneity of variance. Normality of residuals was tested using the UNIVARIATE procedure of SAS. Least square means were separated with the PDIFF option. Main effects and interactions were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Chemical and Physical Analysis of Diets

All diets were formulated to meet or exceed the nutrient requirements of growing-finishing pigs (Table 3.1). Chemical analysis of the diets revealed there was little apparent

difference in comparing the meal, pre-pelleted, and pelleted diets. Chemical and physical traits of the experimental dies through each phase are presented in Tables 3.2 to 3.4.

Growth performance

There were no interactions ($P \geq 0.34$) between diet form and DDGS inclusion during phase 1(d 0 to 35) for any growth performance traits (Table 3.5). There was no effect of diet form on ADG ($P = 0.21$), ADFI ($P = 0.51$) or BW ($P = 0.28$). Pigs fed a pelleted diet were 3.2% more efficient ($P < 0.01$) than meal-fed pigs. Pigs fed 30% DDGS grew 4.3% slower ($P = 0.01$), consumed 3.5% less ($P = 0.03$) feed, and ultimately weighed 1.47 kg less than pigs fed no DDGS at d 35 of the experiment.

There was an interaction between diet form and DDGS inclusion for ADFI ($P < 0.01$) and G:F ($P = 0.03$) for phase 2 (d 36 to 70). In pigs fed meal diets, including 30% DDGS increased ($P = 0.01$) ADFI by 0.14 kg (5.0%) compared with pigs fed no DDGS. However, ADFI was similar between DDGS treatments. Among pigs fed 30% DDGS, pelleting increased ($P < 0.01$) G:F by 7.8%, but there was no effect of pelleting on G:F ($P = 0.32$) in pigs fed no DDGS. Pigs fed pelleted diets had 3.4% greater ($P = 0.03$) ADG compared with pigs fed a meal diet, but there was no effect of DDGS inclusion on ADG ($P = 0.50$). There was no difference in BW ($P = 0.12$) between meal-fed and pellet-fed pigs. There was no effect ($P = 0.09$) of DDGS level on d 70 BW.

There was an interaction between diet form and DDGS inclusion for ADFI for phase 3 (d 71 to 91). Among pigs fed meal diets, 30% inclusion of DDGS increased ($P < 0.01$) ADFI by 0.26 kg (8.4%), but ADFI was similar ($P \geq 0.47$) between pigs fed 30% DDGS and no DDGS pelleted diets. Feeding pelleted diets increased ($P = 0.01$) ADG by 0.06 kg (6.4%). The combination of greater ADG and similar ADFI led to pellet-fed pigs having a 9.2% greater ($P <$

0.0001) G:F meal-fed and were 2.6% heavier ($P < 0.01$) at d 91 than meal-fed pigs. There was no effect ($P = 0.37$) of DDGS inclusion on d 91 BW.

Overall (d 0 to d 91), feeding pelleted diets increased ($P < 0.01$) ADG by 3.6% and there was no effect ($P = 0.46$) of DDGS inclusion. Overall (d 0 to d 91), there was an interaction between diet from and DDGS inclusion for ADFI ($P < 0.01$) and G:F ($P = 0.03$). Among meal-fed pigs, ADFI of pigs fed 30% DDGS was 4.7% greater ($P < 0.01$) than pigs fed no DDGS. However, pelleting diets with 30% DDGS resulted in a 5.2% reduction in feed intake compared with pigs fed 30% DDGS in meal form, whereas pelleting 0% DDGS diets had no effect ($P = 0.33$). There was also an interaction ($P = 0.03$) between diet form and DDGS inclusion for G:F. Among pigs fed a meal diet, those fed 30% DDGS were 2.7% less ($P = 0.02$) feed efficient than pigs fed no DDGS. However, when the diets were fed in pellet form, feed efficiency improved by an average of 5.5% ($P < 0.0001$) regardless of DDGS level, and there was no difference ($P = 0.42$) in efficiency between 0% DDGS-pellet and 30% DDGS-pellet fed pigs.

The 3.6% improvement in rate of gain due to pelleting is similar to the 3-4% improvement in ADG reported by Nemechek et al. (2015). Previous experiments have reported a reduction in feed intake when pelleted diets are fed and have hypothesized that the decrease in ADFI is due to reduced feed wastage (Skoch et al., 1983; Hancock and Behnke, 2001). In the present experiment, the reduction in feed intake due to pelleting was coupled with a 3.6% increase in ADG. When considered together, the improvement in rate of gain of pellet-fed pigs with no difference in feed intake between pellet and meal treatments indicates that improvements in growth performance are due to improved nutrient digestibility of pelleted diets, rather than a reduction in feed wastage. A similar result was reported by Seerley et al. (1962a), in which pellet-fed pigs grew faster than meal-fed pigs when feed intake was equalized across treatments.

Several studies have confirmed that pelleting improves digestibility of starch (Bengala-Freire et al., 1991; Rojas-Martinez, 2015), fat (Xing et al., 2004), DM, N, and GE (Wondra et al., 1995). Because pigs usually consume feed in order to meet caloric requirements, the more digestible the energy in a diet, the less will have to be consumed (NRC, 2012). Improved fat digestibility may also explain the greater magnitude of reduction in intake due to pelleting in pigs fed 30% DDGS compared with 0% DDGS. Conventional distillers dried grains with solubles (DDGS) typically contain 9-15% crude fat (NRC, 2012). Because the diets containing 30% DDGS had a greater concentration of fat, the improved digestibility of fat due to pelleting may have improved the caloric content of the diet such that feed intake was reduced to a greater extent than the diet with no DDGS. The reduced intake of pelleted diets, coupled with increased rate of gain, resulted in a 5.5% improvement in G:F. This improvement is similar to those reported in previous studies investigating the effects of pelleting diets (NCR-42 Committee on Swine Nutrition, 1969; Hanke et al., 1972, Baird et al., 1973; Wondra et al., 1995a,b, Nemechek et al., 2015). In meal form, pigs fed diets with 30% DDGS were less feed efficient than pigs fed 0% DDGS. But, when diets were pelleted, there feed efficiency was improved regardless of DDGS inclusion, and there was no difference in efficiency between pigs fed 0% DDGS or 30% DDGS. The effects of DDGS on feed efficiency have been variable. Several studies have reported no effect of feeding DDGS on G:F (Hill et al., 2008; Xu et al., 2010; McDonnell et al., 2011). However, others have reported that feeding 30% DDGS resulted in reduced G:F compared with diets containing lower levels of DDGS (Gaines et al., 2007; Asmus et al., 2014). The improved G:F with pelleting diets with 30% DDGS observed in the present experiment indicates that negative effects of feeding DDGS may be ameliorated with pelleting, a hypothesis also suggested by Fry et al. (2012).

Gastrointestinal weights and stomach morphology

Although several experiments have reported the effects of diet form on the development of esophagastric ulcers, to the authors' knowledge, this is the first experiment to report the effects of pelleting diets on the weight of the full GI tract and its individual components. The full GI tract of pellet-fed pigs was 0.33 percentage units less ($P = 0.03$) of the ending live weight (**ELW**) compared with meal-fed pigs (Table 3.6), which was due in large part to differences in gut fill. There was an interaction ($P \leq 0.02$) of diet form and DDGS inclusion for absolute esophagus weight and esophagus weight as a percentage of ELW; however the differences were numerically small and likely of little practical importance. There were no differences in small intestine or large intestine weights between pigs fed meal and pellet diets ($P \geq 0.31$). There was no effect of diet form on the weight as a percentage of ELW of the esophagus, stomach or total intestinal mass ($P \geq 0.07$). Similar to BF thickness, pellet-fed pigs also had greater ($P = 0.02$) amount of mesenteric fat surrounding the GI organs, but mesenteric fat weight as a percentage of ELW was not affected ($P = 0.07$) by diet form. Gut-fill, as a percentage of ELW, was less ($P < 0.01$) in pellet-fed pigs than meal-fed pigs, and was the primary reason for pellet fed pigs having full GI tracts that weighed less than those from meal-fed pigs. It also likely directly contributed to the increase in carcass yield of pellet-fed pigs compared with meal-fed pigs. Pelleted diets pass more rapidly through the alimentary canal than meal diets (Seerley et al., 1962b). Thus, a greater amount of the GI tract contents would be excreted during the lairage period. The difference in gut fill may be due to increased digestibility of DM of pelleted diets (Wondra et al., 1995a). As expected, DDGS inclusion increased ($P \leq 0.03$) full GI tract weight, large intestine weight, total intestinal weight and gut fill in terms of absolute weight and as a percentage of ELW. An increase in large intestine weight due to increase in dietary fiber has been reported in

previous studies (Jørgensen et al., 1996; Agyekum et al., 2012). The increase in digestive organ mass in pigs fed high fiber diets has been attributed to hypertrophic growth due to increased peristaltic action, as well as increased capacity to secrete digestive fluids (Agyekum et al., 2012). The incidence and severity of gastric ulcers in pigs is a concern to the pork industry due to increased pig death on the farm and decreased drop value (value of the non-carcass components) for packers, due to discounts on stomachs. In the present experiment, pigs fed pelleted diets had greater ($P < 0.01$) ulceration scores of the esophageal region of the stomach compared with meal-fed pigs, in agreement with previous experiments (Gamble et al., 1967; Wondra et al., 1995a; Nielsen and Ingvartsen, 2000). Despite the increase in ulcer and parakeratosis severity observed in the pellet-fed pigs, there was in fact an improvement in performance. There was no difference ($P = 0.10$) in ulceration and parakeratosis scores between pigs fed 0 % DDGS or a 30% DDGS diet. Although feeding pelleted diets did result in more severe ulcer scores, none of the treatments mean ulceration exceeded a score of 2, and would not likely incur a packer discount.

Carcass characteristics and fresh pork quality

There were no interactions ($P \geq 0.08$) of diet form and DDGS inclusion level on carcass characteristics (Table 3.7). Pigs fed pelleted diets had 2.9% greater ($P = 0.01$) HCW compared with pigs fed a meal diet. In addition, the carcass yield of pellet-fed pigs was 0.45 percentage units greater ($P = 0.02$) than meal-fed pigs. The difference in HCW may be due to increased fat deposition, as carcasses of pellet-fed pigs did not differ ($P = 0.84$) from meal-fed pigs in LEA, but had 0.16 cm more ($P < 0.01$) BF at the 10^{th} rib than meal-fed pigs. The greater carcass yield of pellet-fed pigs is likely due to the combination of decreased gut fill and increased fat thickness. The combination of greater HCW and increased fat thickness, coupled with no

difference in muscling, resulted in pellet-fed pigs having 1.79 percentage units less ($P = 0.04$) estimated carcass lean percentage. Hot carcass weight of pigs fed 30% DDGS was 2.11 kg less ($P = 0.01$) than pigs fed 0% DDGS. Carcass yield of pigs fed 30% DDGS was 0.66 percentage units less ($P < 0.01$) compared with pigs fed 0% DDGS. Loin eye area of 30% DDGS fed pigs was 1.69 cm^2 smaller ($P = 0.04$) than pigs fed 0 % DDGS. The reduction in LEA agrees with previous work reporting a decrease in loin depth in pigs fed a 30% DDGS diet (Whitney et al., 2006) compared with pigs fed 0% DDGS. The decrease in carcass yield in pigs fed 30% DDGS was expected, as the same pigs also had increased full GI tract weight as a percentage of ELW, which was due to having proportionally heavier large intestines. The inclusion of DDGS in the diet did not result in any differences ($P = 0.40$) in BF or ECL% ($P = 0.30$), in agreement with Leick et al. (2010). Several studies have reported the effects of pelleting on carcass characteristics of pigs with contradicting results. Much of the carcass characteristic data available may not be relatable to contemporary swine genetics or management practices. Previous experiments have reported no effect of diet form on carcass characteristics of pigs (Wondra et al., 1995a; Myers et al., 2012, Nemechek et al., 2015). However, other experiments reported feeding pelleted diets tended to increase carcass yield (Fry et al., 2012) and increase BF depth and belly fatness (Matthews et al., 2014).The reason for these contrasting results may be due to differences in marketing schemes, resulting in pigs being marketed at different weights. Wondra et al. (1995a) slaughtered pigs when the heaviest pen in each block weighed 114 kg and reported that diet form did not affect BF depth or carcass yield. But, Fry et al. (2012) slaughtered pigs when the mean weight was approximately 130 kg and reported that feeding pelleted diets tended to increase carcass yield. With the increased digestibility of starch (Bengala-Freire et al., 1991; Rojas-Martinez, 2015) and fat (Xing et al., 2004), increased carcass fatness, similar to the

results in the present experiment, would be expected. With more energy being digested, there should be more energy available for deposition as fat in adipose depots.

There were no interactions of diet form and DDGS inclusion on any fresh loin quality traits ($P \geq 0.23$; Table 3.8). There was no effect ($P \geq 0.07$) of diet form on subjective loin color, **L*** (lightness), **a***(redness), or **b*** (yellowness). Loins of pellet-fed pigs had a lesser ($P = 0.03$) percentage of moisture but did not differ ($P = 0.08$) extractable lipid content compared with meal-fed pigs. There is a lack of reported effects of diet form on pork quality, though there was no indication that feeding a pelleted diet would affect the characteristics of the lean tissue. That hypothesis was confirmed in the present experiment, as there was no effect of diet form ($P \geq 0.27$) on marbling score, firmness score, ultimate pH, drip loss, cook loss, or Warner–Bratzler Shear force. Inclusion of DDGS had no effect ($P \geq 0.15$) on any fresh loin quality traits. This was similar to results of previous experiments that reported that feeding up to 30% DDGS did not have an effect on marbling, ultimate pH, objective color, or proximate composition of the loin muscle (Xu et al., 2010; Leick et al., 2010; Lee et al., 2013).

Conclusions

Feeding growing-finishing pigs a pelleted diet improved growth performance, specifically by increasing ADG and G:F. Pelleting diets with 30% DDGS was especially effective in improving feed efficiency. Furthermore, feeding pelleted diets decreased gut fill and increased carcass fatness, which contributed to a greater carcass yield compared with meal-fed pigs. Feeding a pelleted diet increased HCW and BF and reduced estimated carcass lean. The inclusion of DDGS in diets resulted in expected decreases in carcass yield due to increased GI tract weight, but there were no interactive effects with diet form on carcass characteristics.

Pelleted diets increased the severity of stomach parakeratosis and ulceration, but these were not severe enough in any treatment to negatively affect the drop value of stomachs to packers.

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TABLES

Table 3.1. Ingredient composition of experimental diets, as-fed basis

	Phase 1: d 0 - d 35				Phase 2: d 36 - d 70				Phase 3: d 71 - 91			
Item	Meal - 0% DDGS	Meal - 30% DDGS	Pellet - 0% DDGS	Pellet - 30% DDGS	Meal - 0% DDGS	Meal - 30% DDGS	Pellet - 0% DDGS	Pellet - 30% DDGS	Meal - 0% DDGS	Meal - 30% DDGS	Pellet - 0% DDGS	Pellet - 30% DDGS
Ingredient, %												
Corn	72	47	72	47	78	55	78	55	81	59	81	59
Soybean meal	22	17.3	22	17.3	18.2	12	18.2	12	16	8	16	8
[1]DDGS	0	30	0	30	0	30	0	30	0	30	0	30
Choice white grease	2	2	2	2	1	1	1	1	1	1	1	1
Limestone	0.85	1.15	0.85	1.15	0.8	1.1	0.8	1.1	0.7	1.05	0.7	1.05
Dicalcium phosphate	1.1	0.6	1.1	0.6	0.8	0.35	0.8	0.35	0.7	0.2	0.7	0.2
L-Lysine HCl	0.34	0.35	0.34	0.35	0.21	0.27	0.21	0.27	0.13	0.25	0.13	0.25
DL-Methionine	0.04	-	0.04	-	-	-	-	-	-	-	-	-
L-Threonine	0.09	-	0.09	-	0.03	-	0.03	-	-	-	-	-
Salt	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
[2]Micromineral premix	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
[2]Vitamin premix	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Tylan	1	1	1	1	-	-	-	-	-	-	-	-
Total	100	100	100	100	100	100	100	100	100	100	100	100

[1]DDGS = distillers dried grains with solubles

[2]Provide the following quantities of vitamins and micro-minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride,0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 3.2. Analyzed chemical and physical composition of phase 1 (d 0 - 35) diets, DM basis

	Diet Form					
	Meal		Pre-Pelleting		Pellet	
DDGS Inclusion	0%	30%	0%	30%	0%	30%
Analyzed Composition						
GE, kcal/kg	4575	4654	4535	4651	4495	4623
[1]ME, kcal/kg	4162	4137	4158	4140	4148	4145
DM, %	87.60	87.80	86.55	87.23	86.72	86.89
CP, %	19.19	23.65	19.07	24.19	19.24	23.60
Ash, %	4.47	5.71	4.38	5.39	5.04	5.44
[2]AEE, %	5.49	6.02	5.16	5.33	4.68	5.34
ADF, %	3.50	5.79	4.40	5.82	4.32	4.78
NDF, %	9.22	15.21	10.21	14.51	10.90	12.69
Ca, %	0.65	0.57	0.67	0.72	0.86	0.76
P, %	0.57	0.66	0.61	0.66	0.68	0.71
Indispensable, AA %						
Arg	1.22	1.22	1.16	1.20	1.11	1.24
His	0.51	0.59	0.49	0.60	0.47	0.60
Ile	0.84	0.90	0.79	0.94	0.73	0.93
Leu	1.75	2.30	1.66	2.41	1.57	2.39
Lys	1.36	1.32	1.36	1.28	1.18	1.22
Met	0.32	0.36	0.31	0.37	0.30	0.38
Phe	0.99	1.13	0.92	1.17	0.88	1.17
Thr	0.83	0.85	0.81	0.86	0.74	0.92
Trp	0.25	0.24	0.24	0.22	0.24	0.24
Val	0.89	1.03	0.83	1.05	0.78	1.05
Dispensable, AA %						
Ala	1.02	1.36	0.96	1.40	0.93	1.39
Asp	1.96	1.94	1.81	1.94	1.68	1.99
Cys	0.31	0.39	0.30	0.39	0.30	0.40
Glu	3.44	3.75	3.19	3.81	3.15	3.86
Gly	0.83	0.91	0.76	0.91	0.76	0.92
Pro	1.16	1.57	1.12	1.63	1.10	1.62
Ser	0.88	0.98	0.82	0.96	0.80	0.99
Tyr	0.64	0.77	0.61	0.80	0.59	0.79
Total AA	19.21	21.61	18.15	21.93	17.30	22.12
Physical Characteristics						
Mean particle size, um	780	480	826	661	-	-
[3]SD particle size	2.06	1.97	1.97	1.93	-	-
[4]SA, cm^2/g	75.7	133.8	69.3	85.6	-	-

Table 3.2 Cont.

Angle of repose	34.3	31.3	-	-	17.0	16.6
Bulk density, g/L	693	656	-	-	746	715

[1]ME values were calculated (NRC, 2012)

[2]AEE = acid hydrolyzed ether extract

[3] SD = standard deviation

[4] SA = surface area

Table 3.3. Analyzed chemical and physical composition of phase 2 (d 36 - 70) diets, DM basis

	Meal		Pre-Pelleting		Pellet	
DDGS Inclusion	0%	30%	0%	30%	0%	30%
Analyzed Composition						
GE, kcal/kg	4522	4665	4474	4717	4491	4665
[1]ME, kcal/kg	4153	4142	4154	4135	4161	4148
DM, %	86.57	86.81	86.84	86.06	86.06	86.5
CP, %	16.23	20.76	15.93	20.70	16.28	20.76
Ash, %	3.74	4.39	4.02	4.54	4.16	4.81
[2]AEE, %	4.27	5.88	3.97	5.68	4.48	6.06
ADF, %	4.55	7.04	3.81	7.52	3.59	5.91
NDF, %	11.62	16.28	10.12	17.62	8.47	13.55
Ca, %	0.51	0.58	0.61	0.58	0.64	0.66
P, %	0.49	0.58	0.50	0.59	0.52	0.58
Indispensable, AA %						
Arg	0.88	1.08	0.91	1.09	0.95	1.12
His	0.39	0.54	0.40	0.56	0.42	0.55
Ile	0.60	0.82	0.62	0.83	0.65	0.86
Leu	1.35	2.12	1.40	2.14	1.48	2.18
Lys	0.94	1.09	0.94	1.12	0.98	1.13
Met	0.23	0.35	0.24	0.36	0.23	0.35
Phe	0.73	1.03	0.75	1.03	0.79	1.05
Thr	0.59	0.78	0.60	0.79	0.62	0.80
Trp	0.20	0.20	0.21	0.21	0.21	0.21
Val	0.65	0.94	0.68	0.95	0.72	0.97
Dispensable, AA %						
Ala	0.81	1.26	0.83	1.25	0.86	1.28
Asp	1.36	1.70	1.40	1.70	1.45	1.76
Cys	0.25	0.35	0.25	0.37	0.26	0.36
Glu	2.54	3.32	2.61	3.24	2.70	3.41
Gly	0.62	0.83	0.63	0.83	0.64	1.10
Pro	0.94	1.43	0.96	1.43	1.00	1.47
Ser	0.67	0.92	0.69	0.91	0.70	0.92
Tyr	0.47	0.70	0.51	0.72	0.53	0.75
Total AA	14.22	19.46	14.65	19.52	15.18	20.28
Physical Characteristics						
Mean particle size, um	443	707	855	726	-	-
[3]SD particle size	2.53	1.98	2.00	2.34	-	-

Table 3.3 Cont.

[4]SA, cm^2/g	209.4	81.6	67.7	89.8	-	-
Angle of repose	32.0	30.2	-	-	17.3	18.6
Bulk density, g/L	641	617	-	-	717	673

[1] ME values were calculated (NRC, 2012)

[2]AEE = acid hydrolyzed ether extract

[3] SD = standard deviation

[4] SA = surface area

Table 3.4. Analyzed chemical and physical composition of phase 3 (d 70 -91) diets, DM basis

	Meal		Pre-Pelleting		Pellet	
DDGS Inclusion	0%	30%	0%	30%	0%	30%
Analyzed Composition						
GE, kcal/kg	4503	4672	4524	4712	4495	4664
[1]ME, kcal/kg	4157	4135	4160	4137	4156	4144
DM, %	86.49	87.03	86.48	86.93	86.3	86.64
CP, %	15.40	17.77	15.94	18.64	14.99	18.37
Ash, %	3.61	4.34	3.20	3.99	3.96	4.07
[2]AEE, %	4.33	5.51	4.11	5.78	4.08	5.93
ADF, %	4.47	6.99	3.95	7.39	3.41	4.81
NDF, %	10.49	16.97	10.62	17.88	9.54	15.78
Ca, %	0.52	0.53	0.51	0.43	0.60	0.55
P, %	0.50	0.53	0.46	0.52	0.51	0.54
Indispensable, AA %						
Arg	0.88	0.91	0.84	0.91	0.93	0.90
His	0.39	0.48	0.38	0.47	0.41	0.46
Ile	0.61	0.71	0.59	0.69	0.66	0.68
Leu	1.38	1.93	1.33	1.85	1.46	1.85
Lys	0.88	0.94	0.87	0.94	0.96	0.93
Met	0.24	0.32	0.23	0.31	0.24	0.31
Phe	0.74	0.90	0.72	0.87	0.78	0.87
Thr	0.55	0.68	0.54	0.68	0.59	0.67
Trp	0.18	0.18	0.17	0.18	0.19	0.20
Val	0.67	0.84	0.62	0.82	0.71	0.81
Dispensable, AA %						
Ala	0.81	1.15	0.80	1.12	0.85	1.11
Asp	1.36	1.41	1.33	1.41	1.46	1.40
Cys	0.27	0.31	0.25	0.31	0.27	0.32
Glu	2.54	2.90	2.49	2.82	2.70	2.82
Gly	0.61	0.71	0.61	0.71	0.65	0.70
Pro	0.95	1.31	0.91	1.25	0.98	1.25
Ser	0.66	0.80	0.66	0.79	0.70	0.78
Tyr	0.51	0.64	0.47	0.60	0.51	0.63
Total AA	14.24	17.13	13.83	16.75	15.03	16.69
Physical Characteristics						
Mean particle size, um	1017	860	1059	947	-	-
[3]SD particle size	1.74	1.88	1.70	1.75	-	-

Table 3.4 Cont.

[4]SA, cm^2/g	52.2	64.5	49.5	56.2	-	-
Angle of repose	32.3	31.6	-	-	20.4	22.5
Bulk density, g/L	642	599	-	-	743	681

[1] ME values were calculated (NRC, 2012)

[2]AEE = acid hydrolyzed ether extract

[3] SD = standard deviation

[4] SA = surface area

Table 3.5. Effects of feeding pelleted diets with distiller's dried grains with solubles (DDGS) on growth performance of barrows and gilts

	Diet form × DDGS inclusion[1]					*P*- values		
Item	Meal - 0% DDGS	Meal - 30% DDGS	Pellet - 0% DDGS	Pellet - 30% DDGS	SEM	Diet form	DDGS	Diet form × DDGS
[1]Pen, n	12	12	12	12				
Phase 1 (d 0-35)								
d 0 BW, kg	25.79	25.78	25.68	25.73	0.66	0.07	0.68	0.41
ADG, kg/d	0.91	0.88	0.94	0.89	0.02	0.21	0.01	0.34
ADFI, kg/d	1.91	1.87	1.92	1.83	0.03	0.51	0.03	0.42
G:F	0.474	0.472	0.491	0.485	0.007	< 0.01	0.44	0.68
d 35 weight, kg	57.66	56.60	58.61	56.72	0.97	0.28	< 0.01	0.41
Phase 2 (d 36-70)								
ADG, kg/d	0.97	0.99	1.01	1.01	0.01	0.03	0.50	0.36
ADFI, kg/d	2.72[b]	2.86[a]	2.80[ab]	2.71[b]	0.05	0.40	0.45	< 0.01
G:F	0.357[bc]	0.347[c]	0.363[a]	0.374[a]	0.005	< 0.01	0.90	0.03
d 70 BW, kg	91.53	91.19	94.13	91.39	1.31	0.12	0.09	0.18
Phase 3 (d 71 -91)								
ADG, kg/d	0.92	0.97	1.00	1.01	0.03	0.01	0.18	0.46
ADFI, kg/d	3.11[b]	3.37[a]	3.14[b]	3.15[b]	0.06	0.07	< 0.01	0.02
G:F	0.297	0.288	0.318	0.321	0.007	< 0.01	0.58	0.36
d 91 BW, kg	111.19	111.60	115.31	113.38	1.37	< 0.01	0.37	0.17
Overall (d 0-91)								
ADG, kg/d	0.94	0.94	0.98	0.96	0.01	< 0.01	0.46	0.11
ADFI, kg/d	2.58[b]	2.70[a]	2.62[ab]	2.56[b]	0.04	0.11	0.25	< 0.01
G:F	0.370[b]	0.360[c]	0.383[a]	0.386[a]	0.005	< 0.01	0.27	0.03

[abc]LS means within row lacking a common superscript are different ($P < 0.05$).

[1]Each pen of pigs housed 2 barrows and 2 gilts

Table 3.6. Effects of feeding pelleted diets and distillers dried grains with solubles (DDGS) on gastrointestinal organ weights of barrows and gilts

	Diet Form			DDGS			*P*- values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet form × DDGS
[1]Pen, n	24	24		24	24				
[2]Full GI tract, kg	7.65	7.42	0.11	7.37	7.70	0.11	0.14	0.03	0.08
[2]Full GI tract, %	6.79	6.46	0.11	6.41	6.84	0.11	0.03	< 0.01	0.18
Esophagus, kg	0.07	0.08	0.002	0.07	0.08	0.002	0.02	0.23	0.01
Esophagus, %	0.06	0.07	0.002	0.06	0.07	0.002	0.08	0.05	0.02
Stomach, kg	0.63	0.61	0.01	0.61	0.62	0.01	0.25	0.36	0.66
Stomach, %	0.55	0.53	0.01	0.53	0.55	0.01	0.07	0.10	0.51
Small intestine, kg	1.50	1.53	0.03	1.51	1.52	0.03	0.57	0.86	0.37
Small intestine, %	1.34	1.33	0.03	1.32	1.35	0.03	0.87	0.39	0.27
Large intestine, kg	1.73	1.72	0.03	1.64	1.80	0.03	0.81	< 0.01	0.17
Large intestine, %	1.54	1.49	0.03	1.43	1.60	0.03	0.31	< 0.01	0.27
[3]Intestinal weight, kg	3.24	3.25	0.05	3.17	3.33	0.06	0.94	0.02	0.42
Intestinal weight, %	2.88	2.83	0.04	2.76	2.95	0.04	0.41	< 0.01	0.62
Mesenteric fat, kg	1.68	1.83	0.05	1.77	1.74	0.05	0.02	0.75	0.06
Mesenteric fat, %	1.49	1.59	0.04	1.53	1.55	0.04	0.07	0.86	0.08
[4]Gut fill, kg	2.07	1.66	0.07	1.75	1.98	0.07	< 0.01	0.02	0.19
Gut fill, %	1.84	1.45	0.07	1.53	1.77	0.07	< 0.01	0.01	0.24
[5]Ulceration score	1.27	1.79	0.12	1.40	1.67	0.12	< 0.01	0.10	0.44

[1]Each pen of pigs housed 2 barrows and 2 gilts. Represents the mean of the heaviest barrow and heaviest gilt from each pen.
[2]Full GI tract = weight of the full gastrointestinal tract including esophagus, stomach, mesenteric fat, and the contents of all organs.
[3]Intestinal weight = esophagus + stomach + small intestine + large intestine.
[4]Gut fill = full GI tract - (esophagus + stomach + small intestine + large intestine + mesenteric fat).

Table 3.6 Cont.

[5]Ulceration scores were rated on a 10 point scale where 0 represents a normal stomach with no evidence of ulceration and 10 represented a bleeding ulcer that likely led to the pig's death.

Table 3.7. Effects of feeding pelleted diets and distillers dried grains with solubles (DDGS) on carcass characteristics of barrows and gilts

	Diet Form			DDGS			*P*- values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet form × DDGS
[1]Pen, n	24	24		24	24				
Ending live wt, kg	110.50	113.06	1.30	112.65	110.91	1.30	< 0.01	0.06	0.11
HCW, kg	86.34	88.84	1.12	88.65	86.54	1.12	0.01	0.01	0.17
Carcass yield, %	78.11	78.56	0.14	78.66	78.00	0.14	0.02	< 0.01	0.78
Loin eye area, cm^2	49.49	49.65	0.75	50.41	48.73	0.75	0.84	0.04	0.71
10^{th} rib back fat depth, cm	1.63	1.80	0.04	1.74	1.70	0.04	0.01	0.40	0.08
[2]Estimated carcass lean, %	56.70	54.91	0.59	56.25	55.36	0.59	0.04	0.30	0.10

[1]Each pen of pigs housed 2 barrows and 2 gilts.

[2]Estimated carcass lean percentage= [(8.588 + (0.465 * HCW, lb) - (21.896 * 10th rib fat depth, in) + (3.005 * 10th rib LEA, in^2))/ HCW] * 100.

Table 3.8. Effects of feeding pelleted diets and distillers dried grains with solubles (DDGS) on fresh loin quality of barrows and gilts

	Diet Form			DDGS			*P*- values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet form × DDGS
[1]Pen, n	24	24		24	24				
[2]Color	1.93	1.80	0.05	1.87	1.86	0.05	0.07	0.89	0.48
[2]Marbling	1.32	1.28	0.06	1.31	1.30	0.06	0.70	0.90	0.64
[2]Firmness	1.46	1.55	0.08	1.51	1.49	0.08	0.40	0.83	0.89
[3]L*	50.66	51.32	0.40	51.34	50.63	0.40	0.19	0.16	0.79
[3]a*	8.59	8.34	0.16	8.55	8.38	0.16	0.23	0.38	0.31
[3]b*	4.13	4.16	0.19	4.32	3.97	0.19	0.92	0.15	0.64
Moisture, %	74.52	74.28	0.08	74.23	74.58	0.08	0.03	< 0.01	0.88
Lipid, %	2.57	2.77	0.08	2.77	2.71	0.08	0.08	0.52	0.23
Ultimate pH	5.57	5.58	0.01	5.58	5.58	0.01	0.38	0.85	0.61
Drip loss, %	5.67	5.47	0.26	5.63	5.51	0.26	0.55	0.70	0.90
Cook loss, %	24.90	24.51	0.45	24.45	24.96	0.45	0.47	0.35	0.57
[4]Shear force, kg	3.21	3.10	0.07	3.13	3.18	0.07	0.27	0.62	0.57

[1]Each pen of pigs housed 2 barrows and 2 gilts.

[2]Subjective evaluations based on standards provided by the National Pork Producers Council (Des Moines, IA).

[3]L* = lightness; a* = redness; b* = yellowness.

[4]Warner-Bratzler shear force.

CHAPTER 4: EFFECTS OF FEEDING PELLETED DIETS ON FRESH BELLY CHARACTERISTICS, FAT QUALITY, AND COMMERCIAL BACON SLICING YIELDS OF FINISHING PIGS

ABSTRACT:

A total of 192 barrows and gilts (initial BW = 25.75 kg) were allotted to two blocks, each with 24 pens, based on age. Each pen housed two barrows and two gilts. Four dietary treatment combinations were used: 1.) meal form with 0% distillers dried grains with solubles [DDGS], 2.) meal form with 30% DDGS, 3.) pelleted form with 0% DDGS, or 4.) pelleted form with 30% DDGS. Pigs were slaughtered after a 91 d feeding trial and carcasses were fabricated at 24 h postmortem. Belly dimensions and flop distance were measured. A fat sample from each belly was collected for fatty acid analysis. Bacon was manufactured at a commercial processor and then returned to the University of Illinois Meat Science Laboratory for further evaluation. Data were analyzed as a 2 × 2 factorial arrangement of treatments in a randomized complete block design. Fixed effects were diet form (pellet or meal) and DDGS inclusion (0 or 30%). Replication nested within block was the random effect. Bellies from pigs fed pelleted diets were 5.3% heavier ($P < 0.01$) but, were not different ($P = 0.55$) as a percentage of chilled side weight than pigs fed meal diets. There were no differences ($P \geq 0.11$) in belly dimensions between meal and pellet fed pigs. Belly fat iodine value (IV) of pellet fed pigs was 3.1 units greater ($P < 0.0001$) than meal fed pigs. Pellet fed pigs had heavier belly green weight and those differences persisted throughout processing. Despite pellet fed pigs having a greater IV than meal fed pigs, there were no differences in commercial bacon slicing yields among treatments. Bellies from pellet fed pigs produced more total bacon slices ($P < 0.01$) than bellies from meal fed pigs, but had 3.1% fewer ($P < 0.01$) slices/kg of sliced belly. Inclusion of DDGS resulted in a 0.32 cm

reduction ($P < 0.0001$) in belly thickness, a 4.97 cm reduction ($P < 0.0001$) in flop distance, and a 2.8% reduction ($P = 0.04$) in green weight. Belly fat of DDGS fed pigs had a 7.1 unit greater ($P < 0.0001$) IV than pigs fed no DDGS. There was no effect ($P \geq 0.41$) of DDGS on slicing yields. Overall, bellies from pellet fed pigs were heavier and had greater IV but, did not differ in commercial slicing yields from meal fed pigs. Bellies from pigs fed DDGS were thinner, had decreased flop distance, greater IV, but slicing yield did not differ from bellies from pigs fed no DDGS. Thus, producers can feed pelleted diets to improve growth performance without negatively affecting commercial bacon slicing yield.

INTRODUCTION

Pelleted diets are fed to pigs in order to improve growth performance (Hancock and Behnke, 2001), with pelleting increasing rate of gain and feed efficiency 5 to 8% (Wondra et al., 1995; Myers et al., 2013). The improvement in growth performance is due to increased nutrient digestibility, particularly of fat (Xing et al., 2004) and starch (Bengala-Freire et al., 1991; Rojas, 2015). The increase in fat digestibility also increased the calculated iodine value (IV) of belly fat by 2 to 3 units in pigs fed pelleted diet when compared with pigs fed a meal diet (Matthews et al., 2014; Nemechek et al., 2015). Iodine value is an indicator of fat quality and is often used as a tool to predict the functionality of fat in further processed products. This is particularly true for bacon slicing yields. Reductions in bacon slicing yield have been reported in bellies that have greater proportions of polyunsaturated fatty acids (Shackelford et al., 1990) and greater IV than their contemporaries (Kyle et al., 2014). Calculated IV is poorly related to commercial bacon slicing yields ($r = -0.15$, $P < 0.05$; Kyle et al., 2014). Furthermore, the inclusion of distillers dried grains with solubles (DDGS) increased IV of belly fat, but did not affect commercial bacon slicing yields of barrows (Tavárez et al., 2014). However, the effects of feeding a pelleted diet,

independently or along with, DDGS to growing-finishing pigs on commercial bacon slicing yields are not known. Therefore, the objective of this experiment was to determine effects of feeding pelleted diets without or with 30% DDGS throughout the growing-finishing period on fresh belly characteristics, fat quality, and commercial bacon slicing yields.

MATERIALS AND METHODS

Experimental procedures for the live phase portion of the study were reviewed and approved by the University of Illinois Institutional Animal Care and Use Committee.

Experimental Design and Dietary Treatments

The live phase portion of the experiment consisted of 192 pigs (Génétiporc G-Performer boars × Fertilis-25 sows; Alexandria, MN) that were allocated to 2 blocks based on age on the date of allocation (Overholt et al., 2015). Each block consisted of 6 replications (pens) per treatment with 2 barrows and 2 gilts per pen for a total of 12 replications and 48 pens in the experiment. Pigs were fed in a 3 phase feeding program for 91 d to an average ending live weight of 112.9 kg (Overholt et al., 2015). At the conclusion of the feeding trial, the heaviest barrow and gilt were transported to the University of Illinois Meat Science Laboratory and humanely slaughtered. The remaining 2 pigs in each pen were slaughtered 2 d after the first group. Overall, 6 pigs were removed from the study due to illness or injuries. No pig removal was a results of treatment. Therefore, 186 bellies were used to evaluate belly dimensions, flop distance, fat quality, and processing characteristics.

Carcass Fabrication and Fresh Belly Characteristics

Carcasses were allowed to chill for approximately 24 h after slaughter. The left sides of each carcass were weighed to determine chilled side weight. The left sides were then fabricated into primals and the fresh, skin-on bellies were collected and fabricated to comply with the

Institutional Meat Purchase Specification (**IMPS**) for a #409 pork belly as described by the North American Meat Processors Association (2010). Bellies from the first slaughter day from each block were allowed to equilibrate at 4° C for 72 h and bellies from the second slaughter day within each block were allowed to equilibrate for 24 h at 4° C, such that fresh belly dimensions of pigs within the same block were evaluated on the same day. All bellies were laid flat on a table and covered with butcher paper and cellophane wrap to minimize evaporative loss. Following equilibration, fresh bellies were evaluated for width at the midpoint of the longitudinal axis and length at the midpoint of the latitudinal axis. Belly thickness was calculated as the mean thickness of 8 individual locations of the belly. Thickness at each location was determined by forcing a sharpened back fat probe through the lean side of the belly. Thickness measurements 1 to 4 were collected at the midpoint between latitudinal axis and the dorsal edge at 20%, 40%, 60% and 80% of the length of the belly beginning at the anterior end. Measurements 5 to 8 were collected at the midpoint of the latitudinal axis and the ventral edge at 20%, 40%, 60% and 80% of the length of the belly beginning at the anterior end. Flop distance was determined by measuring the distance between the skin of a belly draped skin-side-down over a stationary bar. A fat tissue sample, containing all 3 fat layers, was collected for fatty acid profile analysis on each belly from the dorsal edge of the anterior end of the belly. Bellies were then appropriately identified and placed in vacuum bags and vacuum sealed. The bellies were frozen (- 29°C) and stored at the University of Illinois Meat Science Laboratory until processing.

Fatty Acid Profile

Samples were prepared using a procedure similar to that described by Tavárez et al. (2012). Fat samples were submerged in liquid N_2 until completely frozen and then pulverized and homogenized in a blender (Waring Products, Torrington, CT) until completely powdered.

The resulting powder was collected and used to obtain fatty acid methyl esters (**FAME**) according to the procedure described by the American Oil Chemists' Society (AOCS, 1998) official method Ce 2-66. The resulting FAME extract were analyzed using a gas chromatograph (Hewlett Packard 5890 Series II; Agilent Technologies, Santa Clara, CA) equipped with an auto-sampler and a DB-Wax capillary column (30 m × 0.25 m × 0.25 μm film coating; Agilent Technologies, Santa Clara, CA). The equipment was operated under a constant pressure of 1.30 kg/cm^2 using He gas as the carrier and a 100:1 split ratio. Temperature of the injector was held at 250°C and the temperature of the flame-ionization detector was held at 260°C. The oven was operated at 170°C for 2 min and programmed to increase 4°C/min up to 240°C and then held constant for 12.5 min. The resulting chromatograph peaks were integrated using Agilent Chemstation software for gas chromatograph systems (version B.01.02; Agilent Technologies, Inc.). Peaks were identified using a gas chromatograph reference standard (GLC 461 A, Nu-check-prep, Elysian, MN). Fatty acids were normalized such that the area under each peak was calculated as a percentage of the total area. Iodine values were calculated using the fatty acid profile data generated using the following AOCS (1998) equation: IV = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723). Total saturated fatty acids, total MUFAs, and total PUFAs were calculated using all the fatty acids within their respective classification. The ratio of unsaturated fatty acids (**UFA**) to SFA was calculated using the fatty acid profile data using the following equation: UFA:SFA = [Σ MUFA + Σ PUFA)/ Σ SFA].

Bacon Manufacturing

Frozen, vacuumed packaged bellies were allowed to thaw at 4°C for approximately 36 h. Thawed bellies were then sorted by treatment and skinned, yielding an IMPS #409 skinless belly.

Bellies were then weighed to collect green weight. Bellies were repackaged with an identification tag and transported in a refrigerated truck to a USDA federally inspected bacon manufacturing facility for further processing. Bellies were injected by treatment group with a typical commercial cure solution formulated to deliver 1.35% salt at a pump uptake of 13%. Bellies were weighed immediately after injection to capture pumped weight in order to calculate the percentage of pump uptake. Pump uptake was calculated with the following equation: Pump uptake = [(Pumped weight – Green weight) / Green weight] × 100. Injected bellies were then hung on smoke house trees with bellies of the same treatment group. Bellies were smoked and thermally processed using a step-up cooking cycle for approximately 4 hr until internal belly temperature was 53.3°C. Smoke house trees were arranged within the smoke house such that a each treatment was placed in the front, center, and back as well as the to the left and to the right of the smokehouse in order to minimize the effect of cold or hot spots during cooking. Thermally processed bellies were chilled for approximately 36 h, before slicing to an internal temperature between -5.6°C and -4.4°C. Cured and smoked bellies were individually weighed to obtain cooked and chilled weight. Cooked-chilled yield was calculated as follows: Cooked-chilled yield = [(Cooked-chilled weight – Green weight)/ Green weight] × 100. Bellies were then pressed and sliced according to the USDA bacon processing plant's standard protocol. Press dimensions were 35 to 38 mm in height × 220 to 240 mm in width. Bellies were oriented in the slicer such that the anterior end was sliced first. The slicer was adjusted to achieve a target of 27 to 31 slices per kg (12 – 14 slices per lb). Completely sliced bellies were sorted by trained facility personnel familiar with bacon grading procedures of the manufacturer. Each sliced and graded belly was placed on a U-board and boxed such that anatomical orientation was maintained. Sliced and

boxed bellies were transported to the University of Illinois Meat Science Laboratory for further analysis.

Sliced Bacon Characteristics

The individual sliced weight of each belly was recorded to calculate commercial bacon slicing yield. Commercial bacon slicing yield was reported as slicing yield, calculated from green weight, and slicing yield, calculated from cooked-chilled weight, using the following equations: Commercial bacon slicing yield calculated from green weight = (Sliced weight / Green weight) × 100; Commercial bacon slicing yield calculated from cooked-chilled weight = (Sliced weight / Cook-chilled weight) × 100 (Kyle et al., 2014; Tavárez et al., 2014). Slabs of sliced bacon were oriented such that the anterior end was to the left and the posterior end was to the right of the observer. The total number of slices was counted for each belly. Number of slices per kg of sliced belly was calculated as follows: number of slices of bacon per kg sliced belly = Sliced belly weight / number of slices. Bellies were then divided into 5 equal zones starting at the anterior end, with approximately equal number of slices in each zone (Zones A, B, C, D, and E) similar to the procedure described by Robles (2004) and Kyle et al. (2014). Two slices from the approximate center of each zone were collected for analysis of proximate composition. A single slice from the approximate center of zones A, C, and E was collected and identified by pig and by location for image analysis. Slices destined for image analysis were placed on rigid, non-stick cardboard, taking care not to distort or stretch the slices. The slices were then placed in vacuum bags, vacuum packaged, boxed and frozen until they could be photographed for image analysis.

Proximate Composition

Proximate composition was determined using 2 slices from each zone of the belly (A, B, C, D, E). Slices were cut into small pieces and then homogenized in a Cuisinart food processor

(CUI DFP-7BC; Cuisinart, East Windsor, NJ). Moisture percentage was determined as described in method 950.46 of the AOAC International (1995). Extractable lipid percentage was determined using the chloroform-methanol solvent method described by Novakofski et al. (1989).

Bacon Slice Image Analysis

Bacon slice image analysis was conducted similar to the procedures described by Kyle et al. (2014). Slices were identified based on anatomical location as blade end (Zone A), center (Zone C), and flank end (Zone E). Slices were photographed using a Nikon D60 camera (Nikon Instruments Inc., Melville, NY) at a standardized distance. A ruler was included in each image in order to calibrate dimensions during image analysis. The background of each image was erased using the magic wand tool such that only the image of the individual slices remained and the resulting image was converted to a TIFF file in Adobe Photoshop CS6 (Adobe Systems Inc., San Jose, CA). Image analysis was conducted using National Institutes of Health image processing and analysis in Java software ImageJ (Abramoff et al., 2004). Threshold values were adjusted as needed within each image to account for variation in lean and fat color. Total slice length, width, total slice area, primary lean area, and secondary lean area (cutaneous trunci [Person et al., 2005]) was calculated by pixel density in ImageJ for each slice. Total lean area was calculated as follows: total lean area = primary lean area + secondary lean area. Percent lean area was calculated as follows: percent lean = (total lean area / total slice area) × 100. Lean to fat ratio was calculated as follows: lean: fat = total lean area / (total slice area – total lean area).

Statistical Analysis

Data were analyzed using the MIXED procedure of SAS (SAS Inst. In., Cary, NC) as 2 × 2 factorial arrangement of treatments in a randomized complete block design. Pen (N = 48)

served as the experimental unit for all fixed variables. Fixed effects were diet form (meal or pellet), DDGS inclusion (0% or 30%), and the interaction between diet form and DDGS inclusion. Block and replication nested within block served as random variables. Assumptions of ANOVA were tested with Levene's test and Brown-Forsythe test for homogeneity of variances. Normality of the residuals was tested using the UNIVARIATE procedure of SAS. Main effects and interactions were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Fresh Belly Characteristics

There was no interaction ($P \geq 0.13$) between diet form and DDGS inclusion for any fresh belly characteristics (Table 4.1). Pigs fed pelleted diets had heavier HCW ($P = 0.01$; Overholt et al., 2015). This difference in carcass weight was reflected in the weights of the skin-on bellies which were 5.3% heavier ($P < 0.01$) than skin-on bellies from meal fed pigs. However, there were no differences ($P = 0.55$) in skin-on belly weights between meal and pellet fed pigs when calculated as a percent of chilled side weight. There were no differences ($P \geq 0.11$) in belly length, width, thickness, flop distance, or thaw loss between meal and pellet fed pigs. There was no effect ($P \geq 0.11$) of DDGS inclusion on skin-on weight, weight as a percent of chilled side weight, length, width, or thaw loss. The inclusion of 30% DDGS resulted in a 3.2 mm decrease ($P < 0.0001$) in belly thickness, and a 4.97cm decrease ($P < 0.0001$) in flop distance, similar to the results of Leick et al. (2010). However, Xu et al. (2010) reported that although feeding 30% DDGS reduces belly firmness score there was no effect on belly thickness but belly fat PUFA concentrations were increased by feeding DDGS. Though belly firmness and thickness are well correlated ($r = 0.59$; $P < 0.0001$; Kyle et al., 2014), belly firmness correlates better with PUFA concentration ($r = - 0.64$; $P < 0.0001$; Kyle et al., 2014).

Fat Quality

There were numerous differences in fatty acid profiles between meal and pellet fed pigs (Table 4.2). Pellet fed pigs had greater ($P \leq 0.03$) concentrations of linoleic acid (C18:2*n*6), α-linolenic acid (C18:3*n*3), and eicosatrienoic acid (C20:3*n*3). Pellet fed pigs had decreased ($P \leq 0.05$) concentrations of capric acid (C10:0), myristic acid (C14:0), myristoleic acid (C14:1), pentadecenoic acid (C15:0), palmitic acid (C16:0), palmitoleic acid (C16:1), margaric acid (C17:0), heptadecenoic acid (C17:1), and oleic acid (C18:1) compared with meal fed pigs. When compared with meal fed pigs, pellet fed pigs had a 2.89% greater ($P < 0.0001$) total PUFAs, 2.09% less ($P < 0.0001$) total MUFAs, and 0.89% less ($P < 0.01$) total SFAs. The greater concentration of PUFA resulted in a 3.08 unit increase ($P < 0.0001$) in IV of pellet fed pigs compared with meal fed pigs. The shift in fatty acid profile was similar to that reported by Nemechek et al. (2015) and Matthews et al. (2014) who observed that pigs fed pelleted diets had a greater proportion of PUFAs leading to a greater IV. When fed to weaning pigs, pelleted diets improved fat digestibility compared with weaning pigs fed diets in meal form (Xing et al., 2004; Rojas, 2015). Pelleting diets increases digestibility of DM, nitrogen, and GE (Wondra et al., 1995) as well as starch (Bengala-Freire et al., 1991; Rojas, 2015). In pigs fed diets in which almost all energy is provided as starch, *de novo* fatty acid synthesis accounts for 86% of all non-essential fatty acids deposited in adipose tissue, typically as SFA and MUFA (Kloareg et al., 2007). When fat is added to the diet, *de novo* synthesis is reduced and exogenous fatty acids from the diet begin to be deposited in adipose tissue at a greater concentration (Azain, 2004). By increasing digestibility of fat, *de novo* fatty acid synthesis is likely reduced, similar to what occurs when dietary fat is increased. Corn contains a relatively high concentration of linoleic acid (NRC, 2012) and with the improved digestibility of fat suppressing *de novo* fatty acid

synthesis, a greater proportion of the linoleic acid from the diet will be deposited in adipose tissue. Furthermore, the increased digestibility of starch will reduce the amount of fat needed to meet energy requirements, further increasing the proportion of dietary fatty acids available for deposition.

When compared with pigs fed no DDGS, pigs fed 30% DDGS had greater ($P \leq 0.01$) concentrations of pentadecenoic acid (C15:0), linoleic acid (C18:2*n*6), γ-linolenic acid (C18:3*n*6), α-linolenic acid (C18:3*n*3), eicosadienoic acid (C20:2*n*6), dihomo-γ-linolenic acid (C20:3*n*6), arachidonic acid (C20:4*n*6), eicosatrienoic acid (C20:3*n*3), and adrenic acid (C22:4*n*6). Pigs fed 30% DDGS also had decreased ($P \leq 0.01$) concentrations of capric acid (C10:0), myristic acid (C14:0), palmitic acid (C16:0), palmitoleic acid (C16:1), heptadecenoic acid (C17:1), stearic acid (C18:0), oleic acid (C18:1), arachidic acid (C20:0) compared with pigs fed 0% DDGS.

Pigs fed DDGS had 6.29% greater ($P < 0.0001$) total PUFA, 2.40% less ($P < 0.0001$) total SFA, and 3.90% less ($P < 0.0001$) total MUFA. Greater proportions of PUFAs resulted in the IV of pigs fed 30% DDGS to be 7.09 units greater ($P < 0.0001$) than pigs fed 0% DDGS. The increase in PUFA concentration and concurrent decrease in both MUFAs and SFAs, in pigs fed DDGS, is in agreement with previous research (Leick et al., 2010; Xu et al., 2010; Tavárez et al., 2012).

Commercial Bacon Processing and Slicing

There was an interaction ($P < 0.01$) between diet form and DDGS inclusion for pump uptake of bellies (Table 4.3). Pump uptake of bellies from 30% DDGS-pellet fed pigs were 0.64 percentage units greater ($P = 0.01$) than 30% DDGS-meal fed pigs, 30% DDGS-meal bellies were 0.58 percentage units greater ($P = 0.02$) than 0% DDGS-meal bellies, and 0% DDGS-meal

pump uptake was 0.79 percentage units greater ($P < 0.01$) than 0% DDGS-pellet bellies. This relationship is likely due to differences in extractable lipid among the treatments as lean tissue is able to retain more brine than adipose tissue citation. Lowe et al. (2013), reported greater pump uptake percentages in bellies of immunologically castrated barrows and hypothesized that this was due to the increased leanness of the bellies, as lipids are hydrophobic and thus have less water holding capacity. However, the interaction of diet form and DDGS inclusion was not reflected in any other processing characteristics, and therefore, is likely of little practical importance.

Differences in fresh, skin-on belly weights were reflected in green weight, pumped weight, cooked weight, and sliced weight as bellies from pellet fed pigs were heavier ($P \leq 0.01$) at all stages of processing compared with those from meal fed pigs. Cooked yield of bellies from pellet fed pigs was greater ($P < 0.01$) than bellies of meal fed pigs. Despite differences in IV between the meal and pellet fed pigs, there was no difference in commercial bacon slicing yield calculated from green weight ($P = 0.16$) or calculated from cooked weight ($P= 0.75$). Iodine value was poorly correlated ($r = -0.15$; $P < 0.05$) with commercial bacon slicing yield (Kyle et al., 2014). This poor correlation is further evidenced in the literature, as reports of the relationship between IV and commercial bacon slicing yield have been inconsistent. Kyle et al. (2014) reported a 3.03 unit difference in IV between barrows and boars which corresponded with a 3.8% difference in commercial bacon slicing yield. However, Tavárez et al. (2014) reported no difference in commercial bacon slicing yield in barrows fed no DDGS and pigs fed 30% DDGS, despite there being an 8.58 unit difference in IV. This implies that there are other factors that contribute to the relationship between IV and commercial bacon slicing yield. For example, belly thickness and moisture content were more strongly correlated with commercial bacon slicing

yield than IV (Kyle et al., 2014). The number of slices from each belly was reflective of green and cooked weights. Bellies from pigs fed a pelleted diet yielded 4.5% more ($P < 0.01$) slices than bellies from pigs fed a meal diet. Pigs fed 0% DDGS yielded 4.2% more ($P < 0.01$) slices than bellies manufactured from pigs fed 30% DDGS. The number of slices per kg of sliced belly was 3.2% greater ($P < 0.01$) in bellies manufactured from meal fed pigs than pellet fed pigs but, there was no effect ($P = 0.08$) of DDGS inclusion on slices per kg of sliced belly. This effect on slice consistency is likely of little consequence to processors marketing bacon on a weight basis. However, for processors marketing bacon on a per slice basis, a greater amount of slices/kg presents an opportunity to capture greater value from each belly.

Slice Image Analysis and Bacon Composition

Visual lean-to-fat ratio (**Lean: Fat**) as well as slice dimensions are important traits that influence consumers purchasing decisions and acceptability of bacon. Bacon from "thick" bellies, which have a less lean: fat ratio than "thin" bellies, are less preferred, and therefore, less likely to be purchased by consumers (Person et al., 2005). Though there was no effect of diet form on fresh belly thickness or width, there was an interaction for bacon slice length ($P < 0.01$) and slice width ($P < 0.01$). Slice length did not differ ($P \geq 0.09$) among bellies from pigs fed no DDGS-Meal, 30% DDGS-Meal, or 30% DDGS-Pellet diets, but slices from bellies of pigs fed no DDGS in pellet form were shorter ($P \leq 0.03$) than bacon slices from any other treatment (Table 4.4). Both Little et al. (2014) and Leick et al. (2010) reported that pigs fed 30% DDGS had longer slices than slices from pigs fed no DDGS and hypothesized that the difference in slice length could be due to the greater concentration of unsaturated fats, contributing to a more elastic structure than slices with a firmer, more saturated fat. Slice width corresponds to thickness of fresh bellies, and slice width often reflects fresh belly thickness. This was not the case in the

present experiment as slices from pigs fed 0% DDGS in pellet form were wider than slices from pigs fed 30% DDGS in pellet form ($P < 0.01$) and pigs fed 0% DDGS in meal form ($P < 0.0001$), but were not different ($P > 0.07$) from slices from pigs fed 30% DDGS in meal form. There was no difference ($P = 0.39$) in slice width between pigs fed 30% DDGS regardless of diet form but both were wider ($P \leq 0.04$) than slices from pigs fed 0% DDGS in meal form. Total slice area of pigs fed pelleted diets was 2.91 cm^2 greater ($P < 0.01$) than slice area of pigs fed meal diets. The inclusion of DDGS had a similar effect, as pigs fed 30% DDGS had slices that were 1.63 cm^2 greater in area ($P = 0.05$) than slices from pigs fed 0% DDGS.

There was no effect ($P = 0.63$) of diet form or DDGS inclusion ($P = 0.37$) on primary lean area. There was an interaction ($P= 0.03$) between diet form and DDGS for secondary lean area. There was no difference ($P = 0.14$) in secondary lean area between pigs fed 30% DDGS regardless of diet form or between pigs fed a meal diet, regardless of DDGS inclusion level. However, pigs fed no DDGS in pellet form had decreased ($P \leq 0.01$) secondary lean area compared with slices from pigs fed 30% DDGS regardless of diet form. Secondary lean area of slices from pigs fed no DDGS in pellet form was not different ($P = 0.08$) from pigs fed no DDGS in meal form. The observed differences in secondary lean area are not likely due to hypertrophy of the *cutaneous trunci*, but are related to the numerical difference in slicing yield between treatments. The size and dimensions of the *cutaneous trunci* muscle changes dramatically from the anterior to the posterior ends of the belly, being the largest in the center and tapering towards the anterior and posterior ends (Kauffman and St. Clair, 1965). During slicing and sorting, the best slices are generally in the center of the belly and slices from anterior and posterior ends are less likely to meet the requirements for a #1 slice. This sorting process leaves the center slices which have a greater proportion of secondary lean. Diet form did not

affect ($P = 0.66$) total lean area but slices from pigs fed 30% DDGS had 1.46 cm^2 greater ($P = 0.05$) total lean area than pigs fed no DDGS. There was an interaction ($P = 0.04$) between diet form and DDGS inclusion on total fat area. Among pigs fed a meal diet, there was no difference ($P = 0.10$) in total fat area between pigs fed 0% or 30% DDGS. Feeding 0% DDGS in pellet form resulted in an 11.0% increase ($P < 0.0001$) in fat area compared with the same diet fed in meal form. Among the pigs fed 30% DDGS, there was no effect ($P = 0.07$) of diet form on total fat area. Among pigs fed a pelleted diet, there was no difference ($P = 0.20$) in total fat area of bacon slices. With no difference in total lean area between diet forms and the increase in fat area due to feeding pelleted diets, bacon slices from pellet fed pigs had a decreased (1. 08 vs 1.17; $P < 0.01$) lean: fat compared with slices from meal fed pigs. This was also reflective of increased 10^{th} rib back fat depths observed in carcasses of pellet fed pigs (Overholt et al., 2015). There was no effect ($P = 0.41$) of DDGS level on average lean: fat. This was similar to a previous experiment by Tavárez et al. (2014), which reported no difference in lean: fat between pigs fed 0% or 30% DDGS, finished to a similar weight. Though differences in slice lean:fat were reflected in differences in estimated carcass lean percentage (Overholt et al., 2015), they were not reflected in the proximate composition of the bacon slices. There was an interaction ($P \leq 0.01$) of diet form and DDGS level for both extractable lipid and moisture content. Bacon from pigs fed 0% DDGS diet in pellet form had a greater ($P \leq 0.01$) percentage of extractable lipid compared with the other three dietary treatments. There were no differences ($P \geq 0.55$) in lipid content between the other three dietary treatments (Table 4.4). The difference in lipid content was reflected in moisture content of the slices. Bacon from pigs fed 0% DDGS in pellet form had the lowest ($P \leq 0.01$) moisture content with no difference ($P \geq 0.54$) among the other three dietary treatments.

Conclusions

Feeding pelleted diets has been implicated in reducing fat quality. Results of this experiment confirm this effect. Iodine value is commonly used as a metric for estimating the quality of bellies and ultimately, the commercial slicing yield of bacon. Feeding pelleted diets to growing-finishing pigs increased the weight of fresh bellies, but negatively affected fat quality through increased proportions of unsaturated fat and consequently increased IV. However, the increase in IV did not appear to be severe enough to negatively affect commercial bacon slicing yields. However, feeding pelleted diets increased the fat content of bellies. Feeding pelleted diets also decreased the number of slices/kg of sliced bellies. While this may not be a concern for processors marketing bacon by weight, this could have implications for processors marketing bacon on a per slice basis, for food service or wholesale. Overall, pig producers can feed pelleted diets to improve growth performance without negatively affecting commercial bacon slicing yields.

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TABLES

Table 4.1. Effects of feeding pelleted diets with distiller's dried grains with solubles (DDGS) on fresh belly characteristics of barrows and gilts

	Diet Form			DDGS			*P*-values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
[1]Pen, n	24	24		24	24				
Belly wt (IMPS # 408), kg	6.39	6.73	0.13	6.62	6.49	0.13	< 0.01	0.13	0.99
% chilled side wt	15.09	15.21	0.18	15.31	14.98	0.18	0.55	0.11	0.68
Length, cm	64.55	64.96	0.36	64.93	64.58	0.36	0.26	0.33	0.46
Width, cm	28.06	28.45	0.26	28.19	28.42	0.26	0.11	0.17	0.72
[2]Thickness, cm	3.58	3.66	0.05	3.78	3.46	0.05	0.12	< 0.0001	0.48
Flop distance, cm	11.64	10.85	0.77	13.73	8.76	0.77	0.44	< 0.0001	0.76
Thaw loss, %	1.63	1.57	0.07	1.61	1.59	0.07	0.55	0.80	0.13

[1]Each pen of pigs housed 2 barrows and 2 gilts

[2]Average thickness was calculated as the average of 8 locations (1 to 4 were from anterior to posterior position of dorsal edge of the belly; 5 to 8 were from the anterior to posterior position of the ventral edge of the belly)

Table 4.2. Effects of feeding pelleted diets with distiller's dried grains with solubles (DDGS) on fatty acid profile of barrows and gilts

	Diet Form			DDGS			*P*-values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
[1]Pen, n	24	24		24	24				
C10:0	0.08	0.08	0.001	0.09	0.08	0.001	0.05	< 0.0001	0.37
C12:0	0.08	0.08	0.001	0.08	0.08	0.001	0.25	0.07	0.04
C14:0	1.40	1.34	0.01	1.41	1.33	0.01	< 0.01	< 0.01	0.95
C14:1	0.01	0.00	0.002	0.01	0.01	0.002	0.05	0.34	0.39
C15:0	0.06	0.05	0.002	0.05	0.06	0.002	< 0.0001	< 0.01	0.16
C16:0	22.66	21.99	0.13	23.07	21.58	0.13	< 0.01	< 0.0001	0.76
C16:1	2.66	2.30	0.03	2.73	2.24	0.03	< 0.0001	< 0.0001	0.09
C17:0	0.37	0.29	0.007	0.32	0.34	0.007	< 0.0001	0.06	0.28
C17:1	0.39	0.30	0.01	0.36	0.33	0.01	< 0.0001	< 0.01	0.38
C18:0	9.66	9.67	0.09	10.09	9.24	0.09	0.94	< 0.0001	0.64
C18:1	43.55	41.92	0.16	44.41	41.05	0.16	< 0.0001	< 0.0001	0.99
C18:2n6	16.13	18.86	0.24	14.55	20.44	0.24	< 0.0001	< 0.0001	0.86
C18:3n6	0.03	0.02	0.003	0.02	0.03	0.003	0.09	< 0.01	0.98
C18:3n3	0.55	0.59	0.01	0.53	0.61	0.01	< 0.01	< 0.0001	0.13
C20:0	0.19	0.19	0.002	0.19	0.18	0.002	0.94	< 0.01	0.70
C20:1n9	0.77	0.76	0.01	0.77	0.75	0.01	0.75	0.09	0.07
C20:2n6	0.69	0.82	0.01	0.65	0.87	0.01	< 0.0001	< 0.0001	0.29
C20:3n6	0.12	0.12	0.002	0.11	0.13	0.002	0.09	< 0.0001	0.67

Table 4.2 Cont.

C20:4n6	0.30	0.30	0.005	0.28	0.32	0.005	0.89	< 0.0001	0.48
C20:3n3	0.09	0.10	0.001	0.09	0.10	0.001	0.03	< 0.01	0.33
C22:0	0.0004	0.0013	0.001	0.0003	0.0013	0.001	0.22	0.21	0.71
C22:1n9	0.0004	0.0015	0.001	0.0004	0.0015	0.001	0.23	0.24	0.81
C22:4n6	0.13	0.13	0.002	0.12	0.15	0.002	0.60	< 0.0001	0.63
C22:5n6	0.06	0.06	0.003	0.06	0.06	0.003	0.10	0.99	0.58
C22:6n3	0.01	0.01	0.003	0.01	0.01	0.003	0.80	0.73	0.83
Total SFA	34.50	33.69	0.20	35.29	32.89	0.20	< 0.01	< 0.0001	0.64
Total PUFA	18.13	21.02	0.26	16.43	22.72	0.26	< 0.0001	< 0.0001	0.86
Total MUFA	47.38	45.29	0.18	48.28	44.38	0.18	< 0.0001	< 0.0001	0.75
[2]IV	70.03	73.11	0.35	68.02	75.11	0.35	< 0.0001	< 0.0001	0.67

[1]Each pen of pigs housed 2 barrows and 2 gilts

[2]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)

Table 4.3. Effects of feeding pelleted diets with distiller's dried grains with solubles (DDGS) on belly processing characteristics and commercial bacon slicing yields

	Diet Form			DDGS			*P* - values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet form × DDGS
[1]Pen, n	24	24		24	24				
Green weight (IMPS #409), kg	5.29	5.64	0.11	5.54	5.38	0.11	< 0.0001	0.04	0.87
Pumped wt, kg	6.15	6.54	0.13	6.40	6.28	0.13	< 0.01	0.19	0.54
Pump uptake, %	16.15	16.08	0.12	15.47	16.76	0.12	0.67	< 0.0001	< 0.01
Cooked and pressed wt, kg	5.54	5.95	0.12	5.80	5.70	0.12	< 0.0001	0.25	0.76
Cooked yield, %	104.61	105.63	0.18	104.48	105.77	0.18	< 0.01	< 0.0001	0.40
Sliced weight, kg	4.93	5.31	0.10	5.17	5.06	0.10	< 0.0001	0.14	0.54
Slicing yield (green wt), %	93.14	94.28	0.56	93.38	94.04	0.56	0.16	0.41	0.26
Sliced yield (cooked weight), %	89.02	89.26	0.51	89.37	88.90	0.51	0.75	0.52	0.16
Number of slices	184	192	2.85	192	184	2.85	< 0.01	< 0.01	0.42
Slices per kg of sliced belly	37.36	36.20	0.33	37.15	36.41	0.33	< 0.01	< 0.08	0.06

[1]Each pen of pigs housed 2 barrows and 2 gilts

Table 4.4. Effects of feeding pelleted diets and distiller's dried grains with solubles (DDGS) on bacon slice characteristics and proximate composition of bacon

	Diet form × DDGS inclusion[1]					*P*- values		
Item	Meal - 0% DDGS	Meal - 30% DDGS	Pellet - 0% DDGS	Pellet - 30% DDGS	SEM	Diet form	DDGS	Diet form × DDGS
[1]Pen, n	12	12	12	12				
Total Area, cm^2	91.48[b]	94.5[a]	95.79[a]	96.02[a]	0.9	< 0.01	0.05	0.09
Primary lean area, cm^2	38.75	39.78	39.01	38.99	0.73	0.63	0.37	0.34
Secondary lean area, cm^2	10.44[bc]	10.84[ab]	9.83[c]	11.35[a]	0.24	0.84	< 0.01	0.03
Total lean area, cm^2	49.2	50.62	48.84	50.34	0.89	0.66	0.05	0.96
Total fat area, cm^2	42.28[c]	43.88[bc]	46.94[a]	45.68[ab]	0.75	< 0.0001	0.81	0.04
Slice length, cm	25.10[a]	25.08[a]	24.50[b]	25.53[a]	0.21	0.67	< 0.01	< 0.01
Slice width, cm	3.43[c]	3.61[ab]	3.72[a]	3.56[b]	0.04	< 0.01	0.86	< 0.01
Lean:Fat	1.17	1.16	1.04	1.11	0.03	< 0.01	0.41	0.17
Proximate composition								
Moisture, %	53.15[a]	52.87[a]	51.14[b]	53.28[a]	0.50	0.10	0.06	0.01
Extractable lipid, %	30.31[b]	30.85[b]	33.28[a]	30.36[b]	0.70	0.06	0.07	0.01

[abc]LS means within row lacking common superscripts are different ($P \leq 0.05$).

[1]Each pen of pigs housed 2 barrows and 2 gilts