CHAPTER 22

Pelleting DDGS Diets for Swine

Introduction

THE USE OF HIGH DIETARY INCLUSION RATES (GREATER THAN 30 PERCENT) OF DDGS in U.S. swine diets has resulted in significant feed cost savings for many years. However, the majority of swine DDGS diets in the Midwestern U.S. are fed in meal form. When DDGS diets must be pelleted, DDGS is often limited to 10 percent of the diet because of concerns of achieving desired pellet quality and pellet mill throughput. As a result, the ability of feed manufacturers and swine producers to capture greater economic value from using higher dietary inclusion rates is diminished because of the diet inclusion constraints imposed on DDGS to meet desired pellet quality and production efficiencies in commercial feed mills.

Pelleting is the most common thermal processing method used in manufacturing swine (Miller, 2012) feeds and provides the advantage of improved feed conversion resulting from reduced feed wastage and improved digestibility of energy and nutrients which has partially been attributed to the partial gelatinization of starch (Richert and DeRouchey, 2010; NRC, 2012). Additional advantages of pelleting diets include reduced dustiness, ingredient segregation during transport, pathogen presence and sorting large particles in mash, along with improved palatability, bulk density, and handling characteristics (Abdollahi et al., 2012; NRC, 2012).

Pelleting Processes

Pelleting is a mechanical process that agglomerates small particles into larger particles using moisture, heat and pressure (Falk, 1985). Commercial pellets can be manufactured to have a wide range of diameters (0.16 mm to 0.75 mm), shapes (triangular, square, oval or cylindrical), and sizes depending the intended animal species and feeding application (California Pellet Mill Co., 2016).

The first step in producing pelleted feeds is particle size reduction of ingredients (primarily grains) using a hammer mill or roller mill. Generally, diets that are to be pelleted have lower average particle size than those fed in meal or mash form to increase pellet durability (Wondra et al., 1995a). Next, ingredients are individually weighed and added to mixers in the desired proportions based on the formulation, and mixed for an appropriate amount of time to achieve a homogeneous mixture. The resulting mash is then subjected to steam-conditioning, in which steam is used to provide the proper balance of heat and moisture (Smallman, 1996). Although steam conditioning requires energy and contributes to the cost of the pelleting process, it increases pellet production rates and pellet durability index (PDI) compared with dry-conditioning (Skoch et al., 1981). After steam is applied to the mash inside the conditioner, the moist, hot mash flows into the pelleting chamber where it is passes through a metal die to form pellets. As the pellets exit the die, they enter a cooler to reduce their temperature from 80 to 90°C down to 8°C above ambient temperature (Zimonja et al., 2007), along with reducing moisture from 15 to 17 percent down to 10 to 12 percent using a stream of ambient air (Robinson, 1976). Fines that are collected in the cooler are returned to the pellet chamber to be subsequently reformed into pellets. For some swine feeding applications, the cool dry pellets pass through a crumbler to form crumbles (broken pellets).

Factors Affecting Pellet Durability, Energy Consumption and Production Rate

The three main goals of manufacturing high quality pelleted poultry diets are to achieve high pellet durability and pellet mill throughput, while minimizing energy cost of the pelleting process (All About Feed, 2012). In general, achieving high pellet durability increases the likelihood that pellets will remain intact from the time of manufacturing until they are consumed. However, almost any adjustment made to increase pellet durability decreases pellet mill throughput and increases energy cost (Behnke, 2006). Producing a high quality pellet is influenced by factors such as type of feed, quantity of lipid, steam additives, particle size, moisture content, die quality, roller quality and the gap between the roller and the die (California Pellet Mill Co., 2016). The primary contributors to energy use and cost during the pelleting process are the production of steam for the conditioning stage, and electricity (measured in kilowatt hours per ton) required to operate the feeders, conditioners, pellet mill and pellet cooling system. Most (up to 72 percent) of the energy used for pelleting is for steam conditioning (Skoch et al., 1983), and Payne (2004) suggested that 15 kilowatt hours per metric ton should be a reasonable goal for pelleting swine diets. In fact, effective decision support systems have been developed to optimize pellet quality, production rate and cost while only slightly decreasing pellet durability (Thomas et al., 1997).

Characteristics of the pellet die affect pellet durability, mill throughput and energy consumption and include: metal properties, hole design, hole pattern, and number of holes (Stark, 2009). The types of metals in the die affect the amount of friction that is generated and subsequent temperature increases as the mash passes through the die (Behnke, 2014). Hole design can be straight bore or relief, but the most important factor related to a pellet die is the thickness (L) of die relative to hole diameter (D), commonly described as the L to D ratio or L:D. As the L to D ratio increases (thicker die), pellet durability increases due to increased friction and die retention time, but pellet mill throughput is reduced and energy consumption is increased (Traylor, 1997).

Physical pellet quality refers to the ability of pellets to remain intact during bagging, storage, and transport until reaching the feeders in the animal production facility, while minimizing the proportion of fines (Cramer et al., 2003; Amerah et al., 2007). Pellet quality is commonly measured by the pellet durability index (PDI; ASAE, 1997). There are five binding mechanisms that are important to achieve a high PDI and include: forming solid bridges, attraction forces between solid particles, mechanical interlocking bonds, adhesion and cohesion forces, as well as interfacial forces and capillary pressure (Thomas and van der Poel, 1996; Kaliyan and Morey, 2006).

Similar to pellet quality, energy consumption of pellet mills depends on variables such as pellet die diameter, die speed, L to D ratio and feed ingredient moisture and chemical composition (Tumuluru et al., 2016). Electrical usage in pellet mills is quantified as units of energy per unit of throughput or time, and is commonly described as kilowatt-hours per ton (kWh/ton; Fahrenholz, 2012).

Production rate of the pellet mill is another important factor that influences PDI and energy consumption. Stark (2009) showed that increasing pellet mill throughput from 545 kg/hr to 1646 kg/hr increased pellet mill efficiency from 73.3 to 112.4 kg/horse power hour, and linearly reduced PDI from 55.4 to 30.2 percent.

Steam conditioning of the mash is considered to be the most important factor in achieving high pellet durability. High conditioning temperature increases PDI and decreases energy consumption (Pfost, 1964) due to decreased mechanical friction (Skoch et al., 1981). Starch gelatinization decreases as conditioning temperature increases (Abdollahi et al., 2011). Changing the pitch of the conditioner paddles (Briggs et al., 1999) can be used to increase retention time (heat) and increase PDI (Gilpin et al., 2002). However, the effects of steam pressure on improving PDI are inconsistent. Cutlip et al. (2008) reported that increasing steam pressure resulted in only small improvements in PDI, whereas Thomas et al. (1997) reported that there is no clear relationship between steam pressure and PDI. This poor relationship was also observed in an earlier study where there was no effect of steam pressure on PDI or production rate (Stevens, 1987). As a result, Briggs et al. (1999) concluded that using 207-345 kilopascals appears to be sufficient steam pressure for achieving a high PDI in pellets.

Many feed manufacturers perceive that diet particle size has a significant influence on PDI of pellets, but there is no strong research evidence to support this. Theoretically, larger particles can cause fractures in the pellets making them more prone to breakage (California Pellet Mill Co., 2016). However, Stevens (1987) showed that particle size of ground corn had no effect on production rate or PDI. Similarly, Stark et al. (1994) reported that reducing diet particle size from 543 to 233 microns only slightly increased PDI. Likewise, Reece et al. (1985) showed that increasing particle size of the diet from 670 to 1289 microns only slightly decreased PDI. Knauer (2014) evaluated the effects of regrinding soybean meal (1,070 vs. 470 µm) and DDGS (689 vs. 480 µm) and the addition of 0 or 30 percent DDGS to swine finishing diets on pellet quality. Results of this experiment showed that adding 30 percent DDGS to diets improved modified PDI by 9.5 percent, regrinding soybean meal improved modified PDI by 4.7 percent, but regrinding DDGS had no effect on modified PDI. Knauer (2014) also evaluated the effects of pelleting diets containing two particles sizes of DDGS (640 vs. 450 µm) and two levels of pellet fines on growth performance of finishing pigs and observed no effects. These results suggest that reducing DDGS particle size by regrinding does not improve pellet quality.

Although diet particle size is not a major factor in achieving desired pellet quality and manufacturing efficiency, diet composition is an important factor due to its effects on die lubrication and abrasion, as well as bulk density of the feed (Behnke, 2006). As a result, various feed ingredients have been characterized based on pelletability factors (Payne et al., 2001). While it is theoretically possible to use these relative feed ingredient pelletability factors as constraints in diet formulation, in practice this is infeasible because the primary goal in diet formulation is to meet the nutritional needs at a low cost, rather than manipulating formulations to optimize PDI.

Starch content of swine diets plays a significant role in determining the PDI after pelleting. Maximum PDI can be achieved in diets containing 65 percent starch, while low starch diets with high protein content decrease pellet durability (Cavalcanti and Behnke, 2005a). In fact, starch and protein content of the diet has been shown to have a greater effect on PDI than conditioning temperature (Wood, 1987). Increasing dietary lipid content decreases PDI (Cavalcanti and Behnke (2005a), and adding 1.5 percent to 3 percent fat has been shown to decrease PDI by 2 percent and 5 percent, respectively (Stark et al., 1994). Furthermore, adding fat to diets before pelleting may not always reduce energy consumption during the pelleting process because there are many interactions among chemical components of diets (Briggs et al., 1999). For example, Cavalcanti and Behnke (2005b) showed that increasing protein content in corn, soybean meal, and soybean oil diets increased PDI.

Moisture content of the mash is another major factor contributing to pellet durability and energy consumption during pelleting. Gilpin (2002) showed that increasing mash moisture content increased PDI and reduced energy consumption. Furthermore, the addition of five percentage points of moisture to mash before pelleting has been shown to increase PDI when pelleting high fat diets (Moritz et al., 2002).

Measuring Pellet Quality

Pellet durability can be measured by a variety of tumbling tests, such as mechanical tumbling and pneumatic tumbling, and include Stoke's ® Tablet Hardness Tester, tumbling box test and the Holman Pellet Tester (Behnke, 2001; Winowiski et al., 1962). The standard pellet durability test used in the feed industry is ASAE S269.4 (ASAE Standards, 2003). This method determines the PDI, which is defined as the percentage of whole pellets remaining after a sifted sample has been tumbled in a tumble box. Another method that has been used with less frequency are the Homen pellet testers manufactured by TekPro (Norfolk, UK). Holmen pellet testers agitate pellets in a pyramid-shaped, perforated chamber, and fines exit the chamber over a 20 to 120 second period to be quantified. Only two studies have compared the use of the ASAE S269.4 method with the Holmen pellet testers. Winowski (1998) reported that the results from both methods were correlated, and Fahrenholz (2012) also reported that the results between the two methods were correlated, but showed that the use of the ASAE tumble box method provided more consistent and repeatable results for measuring PDI than the Holmen testers. Fahrenholz (2012) also showed that while there were significant associations between pellet hardness, pellet density, pellet retention time and initial/final moisture on PDI, these associations are weak and cannot be used as predictors of PDI.

Chemical Characteristics of DDGS

Changes in chemical composition of DDGS continue to evolve as the U.S. ethanol industry adopts new processes to enhance revenue from the production of ethanol and co-products. Because chemical composition of DDGS is an important factor affecting pellet quality, it is useful to understand the variability among sources and the impact of partial oil extraction. Traditionally, the nutrient composition of DDGS (Spiehs et al., 2002; Belyea et al., 2004) contained greater concentrations of crude fat, NDF, and starch, but lower crude protein content than the reduced-oil DDGS currently being produced (Kerr et al., 2013; **Table 1**). However, regardless of these changes in chemical composition, DDGS has very low starch, and relatively high crude fat and NDF content compared with other common feed ingredients, which makes it challenging to when manufacturing high quality pelleted poultry feeds containing high dietary inclusion rates of DDGS, because these chemical components have negative effects on achieving the desired PDI.

California Pellet Mill Company (2016) has classified several common ingredients based on their "pelletability" characteristics. DDGS are classified as having low pelletability and a medium degree of abrasiveness on pellet die. There are several reasons for DDGS to be classified as low pelletability (**Table 2**). First, DDGS has relatively low moisture content which may require adding moisture to the diet in addition to steam provided in the pellet mill, to achieve

Table 1. Comparison of average, range, and changes in nutrient composition of DDGS resulting from partial oil extraction (dry matter basis)

Nutrient	Corn DDGS (> 10 % oil)	Corn DDGS (< 10 % oil)[3]
Moisture %	11.1 (9.8-12.8)[1]	12.5 (10.0-14.5)
Crude protein %	30.8 (28.7-33.3)[1,2]	31.2 (29.8-32.9)
Crude fat %	11.5 (10.2-12.6)[1,2]	8.0 (4.9-9.9)
NDF %	41.2 (36.7-49.1)[1]	32.8 (30.5-33.9)
Starch %	5.3 (4.7-5.9)[2]	2.4 (0.8-3.4)
Ash %	5.2 (4.3 – 6.7)[1,2]	5.4 (4.9-6.1)

[1] Spiehs et al. (2002)
[2] Belyea et al. (2004)
[3] Kerr et al. (2013)

a good quality pellet, but is dependent on the diet inclusion rate of DDGS and the overall moisture content of the diet. However, although the relatively high protein content of DDGS contributes to plasticizing the protein during pelleting that enhances pellet quality, the relatively high oil content in DDGS contributes toward reducing pellet quality but is dependent on diet inclusion rate and amount of other fats or oils added to complete diets. In contrast, the benefit of DDGS having a relatively high oil content is that it can contribute to improved pellet mill production rates. Some types of fiber in feed ingredients contain natural binders that contribute to good quality pellets, but ingredients like DDGS that contain relatively high amounts of fiber actually reduce production rates of pellet mills because fiber is difficult to compress into pellets. The starch content of DDGS is low and may be partially gelatinized during the production process, which is not conducive to improving pellet quality. Furthermore, DDGS has moderate bulk density which can contribute to reduced production rates depending on the density and amounts of other ingredients in the feed formulation. Particle size of DDGS varies from 294 to 1,078 μm among sources (Kerr et al., 2013). Fine and medium ground particle sizes provide more surface area for moisture absorption from steam and results in greater chemical changes which may enhance pellet quality and prevent large particles from serving as natural breaking points for producing fines. Furthermore, low and medium particle size ingredients and diets may improve lubrication of the pellet die and increased production rates.

Pelleting DDGS Diets for Swine

Limited studies have been conducted to evaluate pellet durability of swine diets when DDGS is added, and results are inconsistent. Fahrenholz (2008) observed a reduction in PDI as DDGS inclusion rates increased from 0 percent (90.3 PDI), 10 percent (88.3 percent PDI) and 20 percent (86.8 percent), but suggested that the practical significance of this slight decrease in PDI was of minimal practical importance. Stender and Honeyman (2008) observed a more dramatic decrease in PDI (from 78.9 to 66.8) when comparing pelleted diets containing 0 percent and 20 percent DDGS. However, Feoli (2008) showed that adding 30 percent DDGS to corn-soybean meal swine diets increased PDI from 88.5 to 93.0. Farhenholz et al. (2008) used a pellet die that measured 3.97 mm × 31.75 mm, and a conditioning temperature of 85°C, and found that as DDGS levels increased, PDI values and bulk density decreased. De Jong et al. (2013) found no differences in PDI values (93.3 to 96.9), percentage of fines (1.2 to 8.0 percent), and production rate (1,098 to 1,287 kg/hr) among pelleted corn-soybean diets and 30 percent DDGS diets for nursery pigs using a pellet die of 3.18 mm × 3.81 mm. The inconsistent results from these studies suggest that there are likely interactions among processing variables that may have contributed to difference in PDI of DDGS diets among these studies.

One of these factors may be lipid content of DDGS. As previously discussed, lipid content of diets and feed

Table 2. Summary of feed ingredient characteristics and their impact on pellet quality and pellet mill throughput (adapted from California Pellet Mill Co., 2016)

Ingredient Characteristic	Impact of Pellet Quality	Impact on Pellet Mill Production Rate
Moisture	Increased moisture increases pellet quality	N/A
Protein	High protein content increases pellet quality	N/A
Fat	Greater than 2 percent lipid content decreases pellet quality	High lipid content increases production rate
Fiber	High fiber content may improve pellet quality	High fiber content decreases production rate
Starch	High starch content reduces pellet quality unless gelatinized with high temperature and moisture during pelleting	N/A
Bulk density	N/A	High density increases production rate
Particle size	Medium or fine particles improve pellet quality	Medium or fine particles increase production rate

ingredients affects pellet quality and production rate. Due to partial corn oil extraction being used by the majority of U.S. ethanol plants, oil content of DDGS sources varies from 5 to 13 percent. To evaluate the effect of DDGS oil content on PDI of DDGS diets for swine, Yoder (2016) evaluated the effects of adding 15 or 30 percent reduced-oil, and 15 or 30 percent high-oil DDGS to corn-soybean meal swine finisher diets. Diets were pelleted using conditioning temperatures of 65.6°C or 82.2°C and a 4.0 mm × 32 mm die. Throughput was maintained at a constant rate of 680 kg/hr. Pellet quality was evaluated using 4 pellet durability tests (standard PDI, ASABE S269.4, 2007; modified PDI using three 19-mm hex nuts; Holmen NHP 100 for 60 seconds; Holmen NHP 200 for 240 seconds). Diet inclusion rate (15 or 30 percent) of DDGS and conditioning temperature had no effect on PDI, but PDI was greater for diets containing reduced-oil DDGS (88.0 percent) compared with high oil DDGS (82.8 percent). Furthermore, the method used to determine pellet quality dramatically affected PDI, where the highest value was obtained for standard PDI (95 percent), followed by modified PDI (91 percent), Holmen NHP 100 (89 percent) and Holmen NHP 200 (67 percent). The results of this study indicate that relatively high PDI can be achieved in corn-soybean meal-based swine finishing diets containing up to 30 percent DDGS, and adding reduced-oil DDGS improves PDI by about five percentage points compared with adding high-oil DDGS to the diet. However, caution should be used when comparing PDI values among studies because the use of various PDI test methods can lead to differences in interpretation of acceptable PDI.

Effects of pelleting DDGS diets on energy and nutrient digestibility

Pelleting swine diets has been shown to improve digestibility of starch (Freire et al., 1991; Rojas et al., 2016), lipid (Noblet and van Milgen, 2004; Xing et al., 2004), as well as dry matter, nitrogen and gross energy (Wondra et al., 1995a). Pelleting nursery pig diets containing 30 percent DDGS improved apparent total tract digestibility of dry matter, organic matter, gross energy and crude protein compared to feeding a meal diet (Zhu et al., 2010). More recently, Rojas et al. (2016) evaluated the effects of extruding and pelleting a corn-soybean meal and corn-soybean meal-25 percent DDGS diets on energy and nutrient digestibility. As shown in **Table 3**, pelleting and extrusion improved apparent ileal digestibility of gross energy, starch, crude protein, dry matter,

Table 3. Apparent ileal digestibility (percent) of gross energy, starch, crude protein, dry matter, organic matter, acid-hydrolyzed ether extract, and amino acids in corn-soybean meal diets with and without DDGS and soybean hulls (adapted from Rojas et al., 2016)

Nutritional Component	Type of Processing			
	Meal	Pelleted	Extrusion	Extrusion + Pelleting
Gross energy	66.2^{d}	68.4^{c}	72.7^{a}	71.0^{b}
Starch	96.4^{b}	97.7^{a}	98.0^{a}	98.4^{a}
Crude protein	72.5^{b}	73.6^{b}	77.9^{a}	76.6^{a}
Dry matter	63.5^{d}	65.3^{c}	69.6^{a}	67.9^{b}
Ash	21.7^{c}	24.^{4b}c	32.4^{a}	27.4^{b}
Organic matter	66.2^{c}	67.9^{b}	71.9^{a}	70.4^{a}
Amino acid %				
Arg	88.3^{b}	88.6^{b}	91.6^{a}	91.1^{a}
His	83.1^{b}	84.9^{a}	85.8^{a}	85.6^{a}
Ile	78.8^{c}	81.3^{b}	84.3^{a}	83.7^{a}
Leu	82.2^{c}	84.9^{b}	87.1^{a}	86.4^{a}
Lys	78.0^{c}	79.6^{b}	81.8^{a}	80.9^{ab}
Met	83.3^{c}	86.5^{b}	87.7^{a}	86.7^{ab}
Cys	66.7	68.6	67.9^{a}	67.6
Phe	81.2^{c}	83.9^{b}	87.3^{a}	86.5^{a}
Thr	70.9^{c}	73.3^{b}	75.7^{a}	74.7^{ab}
Trp	78.1^{c}	80.5^{b}	83.2^{a}	83.4^{a}
Val	75.6^{c}	78.4^{b}	80.5^{a}	79.9^{a}

^{a,b,c,d} Means within a row lacking a common superscript letter differ (P less than 0.05) ash, acid hydrolyzed ether extract and amino acids. The greatest improvement in digestibility for most nutrients was achieved with extrusion, and the combination of extrusion and pelleting generally did not improve digestibility of nutrients beyond that obtained with extrusion. Several other studies have shown that apparent ileal digestibility of amino acids improves with pelleting and extrusion (Muley et al., 2007; Stein and Bohlke, 2007; Lundblad et al., 2012), but this is not always the case (Herkleman et al., 1990).

For the diet containing DDGS, pelleting increased ME content by 97 kcal/kg dry matter, extruding increased ME by 108 kcal/kg dry matter, but the combination of extruding and pelleting did not improve ME content compared with feeding it in meal form to growing pigs (Rojas et al., 2016; **Table 4**). Similarly, pelleting the corn-soybean meal diet improved ME content by 81 kcal/kg dry matter, and extruding and pelleting increased ME content by 89 kcal/kg, but extrusion alone did not improve ME content.

Effects of pelleting DDGS diets on growth performance

Several studies have shown that an improvement in feed conversion (Wondra et al., 1995a; Nemechek et al., 2015) and growth rate (Wondra et al., 1995a; Myers et al., 2013; Nemechek et al., 2015) when feeding pelleted diets compared to meal diets to swine. A reduction in feed intake is often observed when feeding pelleted diets compared to meal diets, which has been attributed to a reduction in feed wastage (Skoch et al., 1983; Hancock and Behnke, 2001) and improved energy digestibility (NRC, 2012). Feeding pelleted diets containing 15 percent DDGS had no effect on ADG, reduced ADFI and improved feed conversion compared with feeding 15 percent DDGS diets in meal form to growing-finishing pigs. However, when pelleted diets containing 30 percent DDGS were fed to growing-finishing pigs, there was a trend for improved overall growth rate with no effect on feed intake, and feed conversion was improved compared with feeding meal diets (Fry et al., 2012; Overholt et al., 2016).

Effects of pelleting DDGS diets on carcass composition and yield

Several studies have shown no effect of feeding pelleted or meal diets on carcass characteristics (Wondra et al., 1995a; Myers et al., 2013; Nemechek et al., 2015), but some studies have shown an increase in carcass yield (Fry et al., 2012), as well as increased backfat and belly fat (Matthews et al., 2014) when feeding pelleted diets to pigs. In a recent study, De Jong et al. (2016) compared the effects of feeding pelleted or meal diets containing 15 percent DDGS and showed no differences in hot carcass weight, carcass yield, backfat depth loin depth and percentage carcass lean. In contrast, Overholt et al. (2016) fed pelleted diets to growing-finishing pigs and reported an increase in hot carcass weight, 10th rib backfat thickness and reduced percentage of carcass lean compared with pigs fed meal diets, but there was no effect of DDGS diet inclusion rate (0 or 30 percent), nor were there any effects on loin muscle quality. Although feeding pelleted diets reduced the weight of the gastrointestinal tract and improve carcass yield, feeding diets containing DDGS increased the weight of the gastrointestinal weight and contents resulting in reduced carcass yield.

Effects of pelleting DDGS diets on feed handling and storage

Pelleting DDGS diets is useful for reduce ingredient segregation, improving flowability in bins and feeders, and reducing sorting of different size particles of diets by pigs in feeders (Clementson et al., 2009; Ileleji et al., 2007).

Effects of pelleting DDGS diets on feed contaminated with mycotoxins

Frobose et al. (2015) evaluated the effects of pelleting conditions (conditioning temperatures of 66°C and 82°C and retention times of 30 and 60 seconds within temperature) and the addition of sodium metabisulfate to DDGS contaminated with 20.6 mg.kg deoxynivalenol (DON). Pelleting conditions had no effect on DON concentrations but when sodium metabisulfate was added at increasing concentrations to DON contaminated DDGS, DON concentrations were reduced. When DON-contaminated DDGS diets containing sodium metabisulfate were pelleted and fed to nursery pigs, ADG and ADFI were increased. These results suggest that adding sodium metabisulfate to DON-contaminated DDGS prior to pelleting nursery pig diets is effective in reducing the negative effects of this mycotoxin on growth performance.

Table 4. Metabolizable energy content of a corn-soybean meal diet and a corn-soybean meal-25 percent DDGS diet in meal form or after pelleting (85°C), extruding (115°C), and extruding and pelleting (EP) when fed to growing pigs (adapted from Rojas et al., 2016)

	Corn-soybean meal				Corn-soybean meal-25 percent DDGS			
	Meal	**Pelleted**	**Extruded**	**EP**	**Meal**	**Pelleted**	**Extruded**	**EP**
ME, kcal/kg	3,868^{d}	3,949^{bc}	3,893^{cd}	3,957^{bc}	3,947^{cd}	4,044^{ab}	4,055^{a}	3,926^{cd}

^{a,b,c,d} Means within a row without a common superscript differ (P less than 0.05)

Effects of pelleting on survival of PED virus in contaminated feed

Porcine epidemic diarrhea virus (PEDV) caused devastating effects by dramatically increasing mortality of young pigs in the U.S. swine industry in 2013. This virus can be transmitted by feed and feed ingredients (Dee et al., 2014; Schumacher et al., 2015). However, PEDV is a heat-sensitive virus and the temperature and time of exposure of swine feeds during the pelleting process may reduce the infectivity of PEDV in complete feeds (Pospischil et al., 2002; Nitikanchana, 2014; Thomas et al., 2015). Cochrane et al. (2017) showed that conditioning and pelleting temperatures greater than 54.4°C appear to be effective in reducing the quantity and infectivity of PEDV in swine feed. In fact, results from Cochrane et al. (2017) showed that pelleting diets inactivated PEDV at a faster rate (30 seconds), and at a much lower temperature, than those (145°C and 10 minutes) reported by Trudeau et al. (2016). It is unknown if pelleting swine diets reduces the quantity and infectivity of other pathogens, but appears to be an effective strategy to partially reduce the risk of transmission of PEDV from feed mills to swine farms.

Pelleting increases diet cost

Pelleting diets increases cost (Wondra et al., 1995b), but this increased cost is acceptable if the economic benefits resulting from improved growth performance and reduced mortality exceeds this added cost. In addition to the cost of pelleting DDGS to ship, there is the potential for DDGS to have to be re-ground in order to be added into a diet, and possibly re-pelleted, which adds more cost.

Low PDI and increased fines may decrease growth performance

Pellets that are produced with low PDI, and therefore have increased amount of fines, may negatively impact swine growth performance. Stark et al. (1993) evaluated the effects of pellet quality on the growth performance of pigs in both the nursery and finishing phases. In the nursery phase, pigs fed a pelleted diet with 25 percent added fines had a 7 percent decrease in gain:feed compared to pigs fed a pelleted diet that was screened for fines. In the finishing phase, increasing the amount of fines in the diet resulted in a decrease in gain:feed, thereby decreasing the advantage of feeding a pelleted diet (Stark et al., 1993). However, Knauer (2014) also evaluated the effects of feeding pelleted diets containing two particles sizes of DDGS (640 vs. 450 μm) and two levels of pellet fines and observed no effects on growth performance of finishing pigs.

Low particle size required for pelleting may increase the incidence of gastric ulcers

Gastric lesions and ulcers are a common problem in swine production (Grosse Liesner et al., 2009; Cappai et al., 2013) and contribute to significant financial losses (Friendship, 2006). Hyperkeratosis, mucosal erosions, and bleeding ulcers have been more commonly observed in pigs fed pelleted diets compared to feeding mash diets (Mikkelsen et al., 2004, Canibe et al., 2005; Cappai et al., 2013; Mößeler et al., 2014; Liermann et al., 2015). Although the reasons for this occurrence are not well-defined, several researchers have suggested that diet particle size is a contributing component (Vukmirovic et al., 2017). Vukmirovic et al. (2017) also indicated that further reduction in particle size occurs during the pelleting process, but concluded that from summarizing all available published studies, swine diets containing less than 29 percent of particles less than 400 μm are low risk for ulcer occurrence. De Jong et al. (2016) reported that when pigs were fed a pelleted meal (with or without 15 percent DDGS) for at least 58 days there was a greater prevalence of stomach ulceration and keratinization compared with pigs that were fed meal diets. However, these authors also observed that alternating between feeding pelleted diets with meal diets during the finishing phase may help maintain improvements in feed conversion while reducing the incidence of stomach ulcerations (De Jong et al., 2016). Similarly, Overholt et al. (2016) fed meal or pelleted diets containing 0 or 30 percent DDGS to growing-finishing pigs and found that pigs fed a pelleted diet had greater gastric lesion scores in the esophageal region compared to pigs that were fed a meal diet, but the addition of 30 percent DDGS to the diets had no effects on the incidence of gastric lesions.

Pelleting may increase lipid peroxidation and reduce vitamin and exogenous enzyme activity

Because the pelleting process involves heat and moisture, these conditions can contribute to increased lipid peroxidation (Shurson et al., 2015) and reduced vitamin activity (Pickford, 1992). Jongbloed and Kemme (1990) determined that when swine diets with phytase activity are pelleted at conditioning temperatures ≥ 80°C, phytase activity is reduced which then leads to reduced phosphorus digestibility. While the pelleting process has many different factors that could affect exogenous activity, as conditioning temperatures increase during pelleting, phytase inactivation also increases (Simons et al., 1990).

Prediction equations to improve pellet quality of DDGS diets for swine

The inconsistent results reported in pellet durability, production rates, and energy usage among published studies for swine and poultry indicate that there are many interactions among the various factors that affect these important measures. To address the complexity of these interactions and predict the effects of adding DDGS to swine and poultry diets, Fahrenholz (2012) developed prediction equations to predict PDI and energy consumption of DDGS diets:

PDI = 53.90 – (0.04 × corn particle size, microns) – (6.98 × percent fat) – (1.12 × percent DDGS) – (1.82 × production rate, kg/hr) + (0.27 × conditioning temperature, °C) + (0.04 × retention time, seconds) + (1.78 × die L:D) + (0.006 × particle size × die L:D) – (0.23 × fat percent × DDGS percent) + (0.06 × fat percent × conditioning temperature) + (0.15 × percent DDGS × die L:D)

This prediction equation had an $R^2 = 0.92$ and the difference between predicted and actual PDI was 1.1 (about 1 percent variation). Die L:D ratio has the greatest effect on PDI where decreasing die thickness from 8:1 (common in the industry) to 5.6:1 decreased PDI 10.9 units. Increasing conditioning temperature from 65°C to 85°C increased PDI by 7.0 units, and decreasing supplemental soybean oil content in the diet from 3 percent to 1 percent increased PDI by 5.4 units. Decreasing particle size of ground corn from 462 µm to 298 µm contributed to a small, 0.5 unit increase in PDI. Similarly, reducing feed production rate from 1,814 to 1,360 kg/hr increased PDI by only 0.6 units, and had minimal effect on PDI.

kWh/ton= 55.93 – (0.01 × corn particle size, microns) + (1.88 × percentfat) – (0.05 × percent DDGS) – (30.90 × production rate, kg/hr) – (0.41 × conditioning temperature, °C) + (0.17 × retention time, seconds) – (1.20 × die L:D) + (0.02 × corn particle size, microns × production rate, kg/hr) – (0.0001 × corn particle size, microns × conditioning temperature, °C) – (1.41 × percent fat × production rate, kg/hr) – (0.01 × percent fat × percent DDGS) – (0.21 × percent DDGS × production rate, kg/hr) + (0.004 × percent DDGS × conditioning temperature, °C) + (0.22 × production rate, kg/hr × conditioning temperature, °C) – (0.11 × production rate, kg/hr × retention time, seconds) + (1.21 × production rate, seconds × die L:D)

This prediction equation had an $R^2 = 0.95$ and the difference between predicted and actual kWh/tonwas 0.3 (about 3 percent variation). Increasing conditioning temperature from 65°C to 85°C had the greatest effect on reducing energy consumption (2.7 kWh/ton), while a thinner die L:D (5.6:1) reduced energy use by 1.3 kWh/ton. No other factor (corn particle size – 462 to 298 microns % soybean oil = fat – 1 to 3 percent % DDGS – 0 to 10 percent, production rate – 1,360 to 1,814 kg/hr, or retention time – 30 to 60 seconds) affected energy consumption by more than 1.0 kWh/ton. As shown in the equations, there are multiple interactions among factors. Therefore, if current pelleting conditions do not produce desired PDI or energy consumption, modify other factors to achieve better results.

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