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## Review Article

# The use of maize distiller's dried grains with solubles in pig diets

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**Abstract**
Increasing quantities of maize distiller's dried grains with solubles (DDGS) are being produced in the USA, and the nutritional value of "new generation" DDGS for pigs is much improved compared to traditional DDGS sources in the dry mill ethanol industry. Results from recent studies indicate that "new generation" DDGS is higher in digestible and metabolizable energy, apparent digestible amino acids, and available phosphorus than published values. Satisfactory growth performance is obtained when feeding up to 25% DDGS in nursery diets, provided that pigs weigh at least 7 kg and diets are formulated on a digestible amino acid basis. When grow-finish diets are formulated on a total lysine basis and contain more than 10% DDGS, growth performance may be reduced. The relatively high oil content of DDGS may reduce pork fat quality at increasing levels of the diet. Sows can be fed diets containing up to 50% DDGS in gestation and 20% DDGS in lactation. Feeding these high levels of DDGS to sows may improve litter size weaned in the subsequent reproductive cycle, compared to sows receiving maize-soyabean meal-based diets. However, initial feed consumption may be reduced as the sows adapt to the high DDGS diet. The high available phosphorus content of DDGS reduces the amount of inorganic supplementation needed in the diet while reducing P excretion in manure. Feeding DDGS to grow-finish pigs may reduce the incidence, severity, and length of lesions caused by *Lawsonia intracellularis* during a moderate disease challenge, but not during a severe disease challenge.

**Keywords**
distillers' grains
pigs
distillers' solubles
maize fermentation solubles
maize byproducts
nutritive value
performance

## 1. Introduction

Distiller's dried grains with solubles (DDGS) is a co-product of the dry-milling fuel ethanol and beverage industries. During the production of ethanol, starch from grain is converted to alcohol and carbon dioxide. A graphic illustration of the dry-mill ethanol production process is shown in Fig. 1 [1]. During this process, the concentration of the remaining nutrients in the grain increases by approximately three-fold [2]. The official AAFCO definition of DDGS is "The product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing and drying at least three quarters of the solids of the resultant whole stillage by methods employed in the grain distilling industry" [3].

Corn (maize) is the primary cereal grain used in fuel ethanol production in the USA. Wheat, barley, rye, and sorghum (milo), or combinations of these grains are also used in specific regions of North America and other countries, depending on the quantity and price of grains available. Consequently, type of grain source used will greatly affect the nutrient profile and feeding value of DDGS.

In 2000, annual DDGS production in North America was approximately 3.5 million metric tonnes. Due to the rapid growth of this industry, it is estimated that 7.0 million metric tonnes of DDGS will be produced annually by 2005 (Steve Markham, personal communication, 2003). Up until 2001, 96% of DDGS was fed to dairy and beef cattle in the US, with only 4% being

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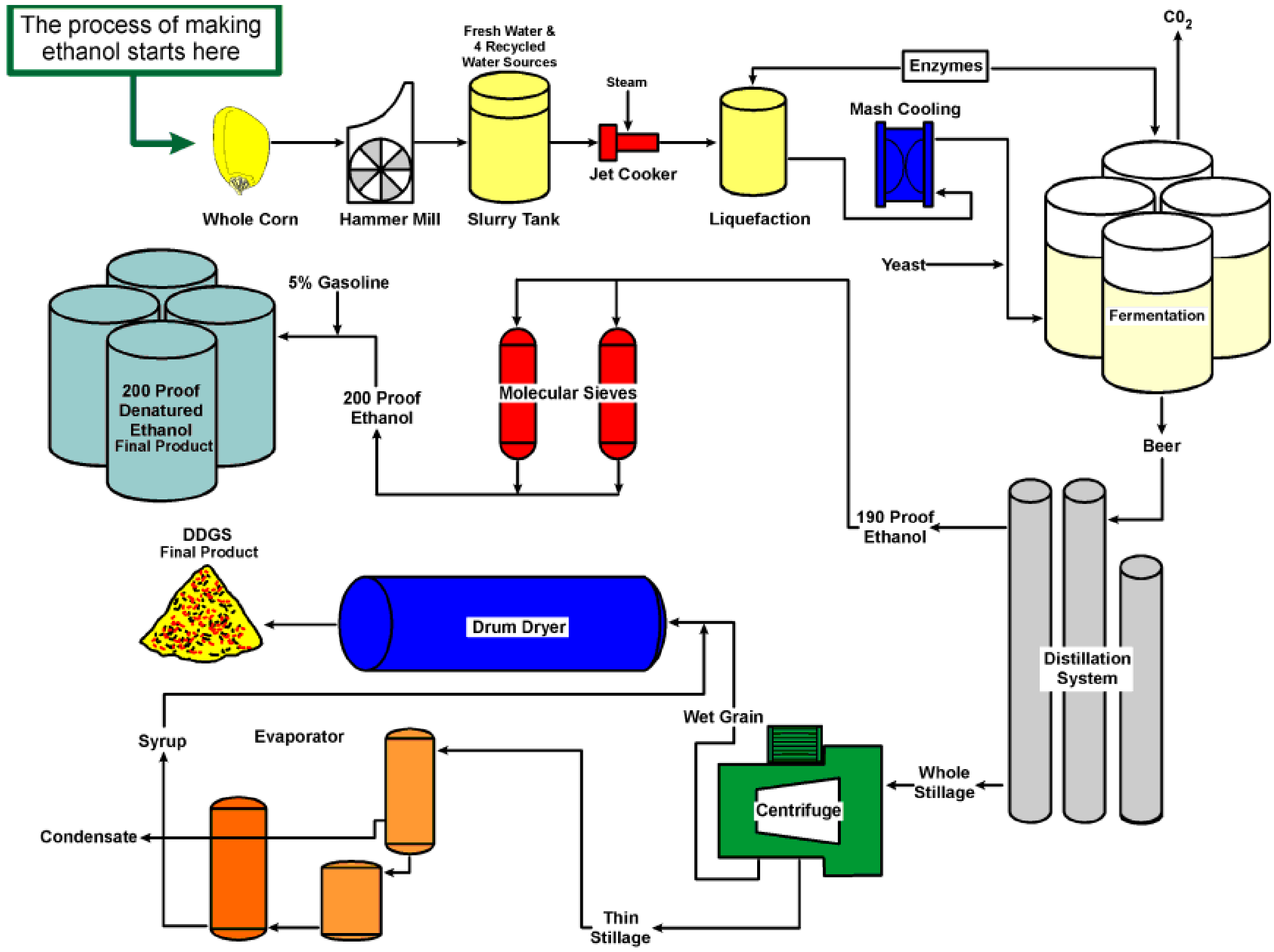


**Figure 1.** Dry-milling ethanol production process (www.exolmn.com/main.htm) [1]

added to pig and poultry feeds. However, it is estimated that 15% of DDGS produced in the US will be used in pig feeds in 2003, during a time when annual DDGS production has also increased (Steve Markham, personal communication, 2003).

Europe has been the primary export market (842,000 metric tonnes in 2002) for US-produced DDGS. In 2002, the major importers of US-produced DDGS were Ireland (298,000 MT), Denmark (106,000 MT), United Kingdom (87,000 MT), Spain (75,000 MT), and Portugal (74,000 MT) (Steve Markham, personal communication, 2003).

During the past 60 years, research has been conducted to evaluate three types of distiller's co-products in pig diets – distiller's dried solubles (DDS), distiller's dried grains (DDG), and DDGS. In the 1940s and 1950s, most of the research on feeding distiller's co-products to pigs focused on evaluating distiller's dried solubles (DDS). Performance trials were conducted to measure growth rate and feed conversion of pigs when DDS was added to starter [4–5] and grow-finish diets [6–7]. Several studies were also conducted to determine if DDS could replace common protein [8–10] and vitamin [11] supplements in corn-based diets during various phases of production.

Beginning in the late 1950s, researchers continued to evaluate growth performance of pigs fed distiller's co-products [12–14], but interest in identifying "unidentified growth factor(s)" in distiller's by-products and their effects on pig growth performance became a research focus [7,15–17].

In the 1970s and 1980s, construction of large-scale ethanol plants occurred and researchers began to focus on evaluating distiller's dried grains with solubles (DDGS). A series of titration experiments were conducted to determine maximal inclusion rates of DDGS that could be added to starter [18–20] and grow-finish diets [21–23]. Additional studies focused on amino acid content of DDGS and the effect of lysine supplementation on performance of pigs fed diets containing DDGS [18,23–24].

From 1986 until 1998, very little research was conducted to evaluate the use of distiller's co-products in pig feeds, even though several new dry mill fuel ethanol plants were being placed in operation. These relatively new, dry-mill ethanol plants use state-of-the-art engineering designs, fermentation technologies, and drying processes compared to older plants that were built and operating decades before.

Although there is considerable variation in the nutrient content and digestibility among DDGS sources, several research studies have demonstrated that DDGS produced by "new generation" ethanol plants has higher levels of essential nutrients than found in NRC [25] and other published sources [26]. Furthermore, recent studies have shown that energy concentration [27], apparent ileal amino acid digestibility [28], and relative phosphorus bioavailability [29] are higher than previously thought. These results have encouraged pig nutritionists and pig producers to reconsider the feeding value of DDGS as an alternative ingredient for use in pig feeds. Additionally, it appears that DDGS may have some "value added" properties along with the nutrients it provides to pig diets. Therefore, the purpose of this review is to summarise our current understanding of the feeding value of high quality, "new generation" maize DDGS in pig diets.

## 2. Nutrient content and variability of DDGS

There has been little incentive to standardize nutrient content and quality of DDGS in the US ethanol industry, primarily because distiller's dried grains with solubles is a co-product of a process designed primarily to produce fuel ethanol. Several factors influence the nutritional and physical characteristics of DDGS including variability of nutrient levels in the maize sources used, proportion of distiller's solubles added to distiller's dried grains before drying, efficiency of converting starch to ethanol, and temperature and duration of drying [30–31]. A complete listing of factors contributing to the variability of nutrient content and digestibility of distiller's co-products is shown in Table 1 [31].

Published feed ingredient tables used by nutritionists do not distinguish nutrient profiles among DDGS sources. Further, discrepancies exist among published feed ingredient tables regarding the nutrient composition of DDGS. The energy density of DDGS (dry matter basis) is listed as 3032 kcal metabolizable energy (ME)/kg by the NRC [25], 3838 kcal ME/kg in the Feedstuffs Reference Issue [32], 3773 kcal ME/kg in the Feed Co-Products Handbook [2] and 3732 kcal ME/kg in the Distillers' Feeds handbook [33]. Crude protein levels (dry matter basis) are less variable but still range from 27.78% in the Feed Co-Products Handbook [2] to 29.6% in the Distillers' Feeds handbook [33]. Total phosphorus levels (dry matter basis) for DDGS cited in the Feed Co-Products Handbook [2], Distillers' Feeds handbook [33] and NRC [25] publication are similar (0.79, 0.82 and 0.83%, respectively), but are much lower than the 1.02% listed in the Feedstuffs Reference Issue [32].

Cromwell *et al.* [34] conducted a study to compare physical, chemical, and nutritional characteristics of nine different sources of DDGS for chicks and pigs. The colour of these sources ranged from very light to very dark, and odour ranged from a sweet smell to a smoky or burned smell. There was also a wide range in nutrient concentration among DDGS sources. Ranges in concentrations of selected nutrients (as fed basis) were:

Dry matter – 87–93%

Crude protein – 23–29%

Crude fat – 3–12%

Ash – 3–6%

Lysine – 0.59–0.89%

Lysine concentration tended to be highest in light-coloured DDGS and lowest in the darkest-coloured DDGS sources. When the four darkest, burned smelling sources were fed to chicks, growth rate, feed intake, and feed conversion were reduced 18, 13 and 6%, respectively, compared to chicks fed the lightest-coloured DDGS. Results from this study suggest that DDGS that is dark in colour and/or has a burned smell should not be used in pig or poultry diets.

Similarly, Spiehs *et al.* [26] collected 118 samples of DDGS from 10 "new generation" ethanol plants in Minnesota and South Dakota during 1998 and 1999 to determine nutrient variability among and within

**Table 1.** Factors influencing nutrient composition of distiller's co-products (Olentine [31])

| | |
|---|---|
| Raw materials | Processing factors |
| Types of grains | Grind procedure |
| Grain variety | Fineness |
| Grain quality | Duration |
| Soil conditions | Cooking |
| Fertilizer | Amount of water |
| Weather | Amount of pre-malt |
| Production and harvesting methods | Temperature and time |
| | Continuous or batch fermentation |
| Grains formula | Cooling time |
| | Conversion |
| | Type, quantity and quality of malt |
| | Fungal amylase |
| | Time and temperature |
| | Dilution of converted grains |
| | Volume and gallon per bushel or grain bill |
| | Quality and quantity of grain products |
| | Fermentation |
| | Yeast quality and quantity |
| | Temperature |
| | Time |
| | Cooling |
| | Agitation |
| | Acidity and production control |
| | Distillation |
| | Type: vacuum or atmospheric, continuous or batch |
| | Direct or indirect heating |
| | Change in volume during distillation |
| | Processing |
| | Type of screen: stationary, rotating or vibratory |
| | Use of centrifuges |
| | Type of presses |
| | Evaporators |
| | Temperature |
| | Number |
| | Dryers |
| | Time |
| | Temperature |
| | Type |
| | Amount of syrup mixed with grain (fibrous) portion |

plants, and compared these nutrient levels to reference values published by the NRC [25], Feedstuffs Reference Issue [32] and Heartland Lysine [35], along with a comparison with nutrient values obtained from DDGS produced by an older Midwestern ethanol plant. "New generation" DDGS is generally golden to light brown in colour and has a sweet, fermented smell compared to DDGS from older Midwestern ethanol plants that produce a dark coloured DDGS. Digestible energy (DE), ME, and nitrogen-free extract levels were calculated based upon actual proximate analysis values and published DE and ME prediction equations [36]. Means (dry matter basis) and coefficients of variation for each nutrient among all plants are summarised in Table 2.

Among the amino acids analysed, lysine was the most variable (CV=17.3%), followed by methionine (CV=13.6%). Nutrient levels of "new generation" DDGS were higher in crude fat, neutral detergent fibre, DE, ME, phosphorus, lysine, methionine, and threonine and lower for dry matter, acid detergent fibre, and calcium than NRC [25] values. Nutrient values tended to be different between years for ash, DE, manganese, zinc, cystine ($P < 0.10$), fat, total digestible nutrients, ME, methionine, isoleucine (P

**Table 2.** Comparison of nutrient composition of "new generation" DDGS to "old generation" DDGS and published reference values (dry matter basis).

| | New generation DDGS[c] | Old generation DDGS | NRC [25] | Heartland Lysine [35] | Feedstuffs Reference Issue [32] |
|---|---|---|---|---|---|
| Dry matter, % | 89.1 (1.2) | 89.5 | 93.0 | 90.8 | 93.0 |
| Crude protein, % | 30.5 (1.4) | 29.0 | 29.8 | 28.5 | 29.0 |
| Crude fat, % | 10.7 (1.0) | 9.7 | 9.0 | - | 8.6 |
| Crude fibre, % | 8.9 (0.6) | 7.4 | - | - | 9.1 |
| Ash, % | 5.8 (0.7) | 8.0 | - | - | 4.8 |
| NFE, % | 44.2 (2.2) | 45.9 | - | - | - |
| ADF, % | 15.7 (2.1) | 16.7 | 17.5 | - | - |
| NDF, % | 43.5 (3.0) | 38.0 | 37.2 | - | - |
| Calculated DE, kcal/kg | 3990 (3.2)[a] | 3879[a] | 3449 | - | - |
| Calculated ME, kcal/kg | 3749 (3.3)[b] | 3661[b] | 3038 | - | 3848 |
| Arginine, % | 1.20 (9.1) | 0.92 | 1.22 | 1.21 | 1.08 |
| Histidine, % | 0.76 (7.8) | 0.61 | 0.74 | 0.75 | 0.65 |
| Isoleucine, % | 1.12 (8.7) | 1.00 | 1.11 | 1.09 | 1.08 |
| Leucine, % | 3.55 (6.4) | 2.97 | 2.76 | 3.27 | 2.90 |
| Lysine, % | 0.85 (17.3) | 0.53 | 0.67 | 0.81 | 0.65 |
| Methionine, % | 0.55 (13.6) | 0.50 | 0.54 | 0.63 | 0.65 |
| Phenylalanine, % | 1.47 (6.6) | 1.27 | 1.44 | 1.43 | 1.29 |
| Threonine, % | 1.13 (6.4) | 0.98 | 1.01 | 1.11 | 1.02 |
| Tryptophan, % | 0.25 (6.7) | 0.19 | 0.27 | 0.20 | 0.22 |
| Valine, % | 1.50 (7.2) | 1.39 | 1.40 | 1.43 | 1.43 |
| Ca, % | 0.06 (57.2) | 0.44 | 0.22 | - | 0.38 |
| P, % | 0.89 (11.7) | 0.90 | 0.83 | - | 1.02 |
| K, % | 0.94 (14.0) | 0.99 | 0.90 | - | 1.08 |
| Mg, % | 0.33 (12.1) | 0.40 | 0.20 | - | 0.38 |
| S, % | 0.47 (37.1) | 0.51 | 0.32 | - | 0.32 |
| Na, % | 0.24 (70.5) | 0.28 | 0.27 | - | 0.86 |
| Zn, ppm | 98 (80.4) | 80 | 86 | - | 91 |
| Mn, ppm | 16 (32.7) | 50 | 26 | - | 32 |
| Cu, ppm | 6 (20.4) | 14 | 61 | - | 54 |
| Fe, ppm | 120 (41.1) | 219 | 276 | - | 323 |

[a] Calculated DE = 4151 – (122 x % Ash) + (23 x % CP) + (38 x % EE) – (64 x % crude fibre)
[b] Calculated ME = DE x [(1.003 – (0.0021 x % CP)]
(Noblet and Perez [36])
[c] Values in parentheses are coefficients of variation among 10 "new generation" DDGS sources.

< 0.05), calcium, phosphorus, potassium, magnesium, and copper (P < 0.01). These results suggest that gross energy, phosphorus, lysine, methionine, and threonine levels are higher in "new generation" DDGS compared with published NRC values [25].

Additional studies conducted at the University of Minnesota have shown that DDGS produced in "new generation" ethanol plants is higher (dry matter basis) in digestible and metabolizable energy [27] (Table 3), higher in apparent ileal digestible amino acids [28] (Table 4), and higher in available phosphorus [29] (Table 5) than DDGS produced in older, more traditional ethanol plants. Although DDGS contains a significant amount of crude fibre (7 to 8%), it also contains a high amount of crude fat (9 to 10%, on an "as fed" basis) which results in DDGS containing an energy value (DE, 3965 kcal/kg; ME, 3592 kcal/kg) similar to that found in maize (DE, 3961 kcal/kg; ME, 3843 kcal/kg) on a dry matter basis (Table 3). The apparent ileal amino acid digestibility coefficients for lysine, methionine, and threonine were higher (P < 0.01) in "new generation" DDGS compared with values from dark coloured, "old generation" DDGS and values published by the NRC [25], resulting in higher levels of apparent ileal digestible amino acids as shown in Table 4. Perhaps the biggest nutritional advantage of feeding DDGS to pigs is its high available phosphorus content. It is well known that maize is low in phosphorus (0.28%), and relative phosphorus bioavailability is also low (14%). However, the phosphorus content of "new generation" DDGS is 0.89% (dry matter basis) and the relative bioavailability of phosphorus appears to be increased to 90% after the maize has gone through the fermentation process (Table 5).

## 3. Recent pig feeding trials using "new generation" DDGS

### *3.1. Starter*

Whitney and Shurson [37] conducted two experiments to determine the effects of increasing dietary levels (0 to 25%) of "new generation" DDGS on growth performance of early weaned pigs. A total of 96 crossbred pigs (body weight 6.18 ± 0.14 kg) were blocked by gender and ancestry, and pigs within each block were randomly assigned to one of six dietary treatments (4 pigs/pen, 4 pens/treatment) in each of two growth performance experiments. Dietary treatments consisted of providing 0, 5, 10, 15, 20, or 25% DDGS during Phases 2 and 3 of a 3-phase nursery feeding programme. Pigs in experiment 1 were slightly older (19.0 vs. 16.9 days of age) and heavier (7.10 vs. 5.26 kg) at the beginning of the experiment compared to pigs in experiment 2. All pigs were provided a commercial pelleted diet for the first 4 days post-weaning, and were then switched to their respective experimental Phase 2 diets (fed for a subsequent 14 days), followed by Phase 3 experimental diets (fed for an additional 21 days). Experimental diets were formulated to contain equivalent apparent ileal digestible lysine (1.35 and 1.15%) and methionine + cystine (0.80 and 0.65%), ME (3340 and 3390 kcal/kg), calcium (0.95 and 0.80%), and total phosphorus (0.80 and 0.70%) within Phases 2 and 3, respectively.

Overall growth rate, ending body weight, and feed conversion of pigs were similar among dietary treatments regardless of dietary DDGS level fed for both experiments. In experiment 1, feed intake was unaffected by dietary treatment (P < 0 .01). In experiment 2, however, increasing dietary DDGS level linearly decreased feed intake (P < 0.02) during Phase 2, and tended to decrease voluntary feed intake (P < 0.09) over the length of the experiment. These results suggest that "new generation" DDGS can be included in Phase 3 diets for nursery pigs at dietary levels up to 25%, without negatively affecting growth performance after a 2-week acclimation period. Satisfactory growth performance can also be achieved with the addition of up to 25% "new generation" DDGS in Phase 2 diets for pigs weighing at least 7 kg in body weight. Including these high levels immediately post-

**Table 3.** Comparison of energy values for DDGS (dry matter basis)

| | "New" DDGS calculated | "New" DDGS Trial average | "Old" DDGS calculated | DDGS NRC [25] |
|---|---|---|---|---|
| DE, kcal/kg | 3965 | 4011 | 3874 | 3441 |
| ME, kcal/kg | 3592 | 3827 | 3521 | 3032 |

Maize: DE (kcal/kg) = 3961, ME (kcal/kg) = 3843 (NRC [25])

**Table 4.** Comparison of apparent ileal digestible amino acid composition of DDGS (dry matter basis) between "New Generation" DDGS, "Old Generation" DDGS, and values published in NRC [25]

| | "New Generation" DDGS | "Old Generation" DDGS | DDGS NRC [25] |
|---|---|---|---|
| Arginine, % | 0.90 | 0.60 | 0.88 |
| Histidine, % | 0.51 | 0.30 | 0.45 |
| Isoleucine, % | 0.72 | 0.42 | 0.73 |
| Leucine, % | 2.57 | 1.84 | 2.10 |
| Lysine, % | 0.44 | 0.00 | 0.31 |
| Methionine, % | 0.32 | 0.24 | 0.39 |
| Phenylalanine, % | 0.89 | 0.68 | 1.09 |
| Threonine, % | 0.62 | 0.36 | 0.56 |
| Tryptophan, % | 0.15 | 0.15 | 0.14 |
| Valine, % | 0.92 | 0.51 | 0.88 |

**Table 5.** Comparison of phosphorus level and relative availability of DDGS and maize (dry matter basis)

| | "New" DDGS | "Old" DDGS | DDGS NRC [25] | Maize NRC [25] |
|---|---|---|---|---|
| Total P, % | 0.89 | 0.90 | 0.83 | 0.28 |
| Relative P availability, % | 90 | No data | 77 | 14 |
| Available P, % | 0.80 | No data | 0.64 | 0.04 |

weaning, however, may negatively influence feed intake, resulting in poorer initial growth performance.

### 3.2. Grower-finisher pigs

Whitney *et al.* [38] conducted a growth performance and carcass evaluation study to determine the effects of feeding increasing levels of "new generation" DDGS in grow-finish diets, when diets are formulated on a total lysine basis. A total of 240 (28.4 ± 0.8 kg) crossbred pigs ((Yorkshire x Landrace) x Duroc) were randomly assigned to one of 4 dietary treatment sequences in a 5-phase grow-finish feeding programme. Dietary treatments consisted of maize-soyabean meal diets containing 0, 10, 20, or 30% DDGS. Time of changing to the subsequent diet phase was based on average pen weight within dietary treatment sequence. Pigs were slaughtered and carcass data were collected when average pen weight reached 115 kg.

Pigs fed the 20 or 30% DDGS diets tended to have reduced ADG ($P < 0.10$) compared to pigs fed 0 or 10% DDGS diets, but ADFI was unaffected ($P > 0.10$) by dietary treatment. Feed/gain tended to increase ($P < 0.10$) when pigs were fed the 30% DDGS diets compared to pigs fed the 0, 10 and 20% DDGS diets. Dressing percentage decreased linearly ($P < 0.03$) with increasing dietary DDGS level, but slaughter weight was also lower ($P < 0.05$) for pigs fed 20 or 30% DDGS compared to pigs fed the 0 and 10% DDGS diets. Loin depth tended to be lower in pigs fed the 30% DDGS diets ($P < 0.10$), but backfat depth and percentage lean did not differ ($P > 0.10$) between dietary treatments. Results from this study suggest that when grow-finish diets are formulated on a total amino acid basis, no more than 10% DDGS should be included in the diet for optimal performance and carcass composition. Dietary inclusion levels greater than 10% DDGS may provide satisfactory growth performance if diets are formulated on a digestible amino acid basis. It is recommended that no more than 20% DDGS be included in diets for grow-finish pigs because of concerns of increased iodine value and soft pork fat due to the relatively high oil content of DDGS.

### 3.3. Gestating and lactating sows

Three studies have been conducted to determine the optimum inclusion rate of DDGS in diets for sows during gestation and lactation [39–41], and recommendations for maximum dietary inclusion rates have been published based upon results obtained in 1964 by Thong *et al.* and in 1995 by Monegue and Cromwell [2,42]. As a result of limited information on feeding DDGS to sows, current recommendations for DDGS inclusion for use of DDGS in sow diets are somewhat different. The Feed Co-Products Handbook [2] lists the maximum inclusion rate for DDGS to be up to 50% in gestation diets and up to 20% in lactation diets. The Pork Industry Handbook, however, recommends slightly lower levels of DDGS usage, suggesting up to 40% in gestation diets and a maximum inclusion rate of 10% in lactation diets [42].

Thong *et al.* [39] conducted an experiment using 64 gilts to evaluate the use of DDGS as a replacement for soyabean meal in a maize-soyabean meal diet fed during gestation. To conduct this experiment, sows were fed diets containing either 0, 17.7 or 44.2% DDGS during gestation. All diets were formulated to contain 0.42% total dietary lysine. Number of pigs farrowed per litter and average pig birth weight were not significantly affected ($P > 0.10$) by dietary treatment. The authors concluded that DDGS could replace soyabean meal on a lysine-equivalent basis as a source of supplemental amino acids at levels up to 44.2% of the diet for gestating sows.

Monegue and Cromwell [40] compared reproductive performance of sows fed a fortified maize-soyabean meal diet with sows fed diets containing 40 or 80% maize gluten feed and sows fed diets containing 40 or 80% DDGS during gestation. A total of 90 parity 4 crossbred sows (18 sows/dietary treatment) were used in this study. Diets contained similar levels of total lysine and were fed at different levels to equalize ME intake at 6.2 Mcal/sow/day. Sows were allowed to consume a fortified maize-soyabean meal diet *ad libitum* during the subsequent 28-day lactation period. Farrowing rates averaged 91% and were not affected by dietary treatment ($P = 0.20$). Gestation weight gains tended to be greater in sows fed the maize gluten feed and DDGS diets indicating that the energy in these maize by-products was well utilised. Lactation feed intake and sow weight loss during lactation were similar among dietary treatments. Litter size at birth and pig birth weights were not affected by dietary treatment ($P = 0.20$), although numerically, sows fed the 80% DDGS had slightly smaller litters. Litter size weaned and litter weaning weights were not different ($P = 0.20$) among dietary treatments, although feeding the 80% maize gluten feed diet and the DDGS diets during lactation numerically reduced litter size weaned and increased individual pig weight at weaning. There were no differences ($P = 0.20$) in litter weaning weight and pig survival percentage to weaning among dietary treatments. Days for sows to return to oestrus following weaning were similar among dietary treatment groups and averaged 4.7 days. The authors concluded that diets containing high levels of maize gluten feed and DDGS, up to 80% of the gestation diet, are well utilised, and do not appear to impair reproductive or lactation performance.

More recently, Wilson *et al.* [41] conducted a two-parity study utilising 93 multiparous sows to determine the effects of feeding diets containing 50% DDGS in gestation and 20% DDGS in lactation on sow reproductive performance. Nutrient balance was also determined from day 100 to day 105 of pregnancy using 14 gestating sows. Sows were allotted based on parity and initial body weight to one of two gestation diets (0 or 50% DDGS, maize-soyabean meal-based diets), and one of two lactation diets (0 or 20% DDGS, maize-soyabean meal-based diets). Sows were fed a daily amount of feed based on 1% of sow body weight plus 100, 300 and 500 g per day on days 0 to 30, 31 to 60, and 61 to 90 days of gestation, respectively. Sows were provided *ad libitum* access to feed during lactation. Sows remained on their respective dietary treatment combinations through two reproductive cycles.

No differences in sow gestation weight gain, pigs born alive per litter, litter birth weight, or average pig birth weight were observed between sows fed 0 and 50% DDGS diets during gestation for both reproductive cycles ($P > 0.10$). Dietary treatment combination had no effect on litter size, litter birth weight, or litter weaning weight during the first reproductive cycle, but sows fed 0% DDGS gestation and lactation diets weaned fewer pigs per litter during the second reproductive cycle ($P < 0.05$). Pre-weaning mortality was higher ($P < 0.05$) for sows fed the 50% DDGS gestation diet and 20% DDGS lactation diet compared to other treatment combinations during the first reproductive cycle, but dietary treatment combinations had no effect on pre-weaning mortality during the second reproductive cycle.

Sows fed the 0% DDGS gestation diet and the 20% DDGS lactation diet had lower lactation feed intake ($P < 0.01$), which primarily occurred within the first 7 days of lactation, but this effect was not observed during the second reproductive cycle. Wean-to-oestrus interval was higher ($P < 0.001$) for sows fed the 0% DDGS gestation and lactation diet treatment combination compared to sows fed the 50% DDGS gestation, 20% DDGS lactation diet combination and the 50% DDGS gestation, 0% DDGS lactation diet combination during the first reproductive cycle. No wean-to-oestrus interval differences were observed during the second reproductive cycle. Sows fed the 50% DDGS diet in late gestation tended to consume more energy, nitrogen, sulphur, and potassium, and had greater nitrogen, sulphur ($P < 0.05$), and phosphorus ($P < 0.10$) retention than sows fed the 0% DDGS gestation diet. These results indicate that feeding a gestation diet containing 50% DDGS will support good reproductive performance. However, feeding a 20% DDGS lactation diet may reduce feed intake during the first week post-partum if sows were fed a maize-soyabean meal diet during gestation and not provided an adjustment period to adapt to a high DDGS diet during lactation.

## 4. DDGS and manure management

Spiehs *et al.* [43] conducted a 10-week trial to measure odour and gas characteristics of pig manure, and energy, nitrogen, and phosphorus balance of grow-finish pigs fed on maize-soyabean meal-based diets containing 0 or 20% DDGS. Sixteen PIC barrows weighing $57.6 \pm 3.8$ kg were randomly assigned to one of two dietary treatments (8 pigs/treatment): control (0% DDGS) and 20% DDGS. A three-phase diet sequence was used. Calculated total lysine and phosphorus levels were identical for both diets within each phase. Manure from each pig, housed in collection cages, was collected daily except during the last 3 days of weeks 2, 6 and 10, when total faecal and urinary excretion was collected for nutrient balance measurements. Urine and faeces were mixed and emptied into simulated anaerobic manure pits according to the respective dietary treatments. Air samples were collected weekly from the headspace above each simulated pit and analysed for $H_2S$ and $NH_3$. Air samples collected during weeks 0, 2, 5 and 8 were evaluated for odour detection level utilising a human odour panel and olfactometer.

Dietary treatment had no effect on $H_2S$, $NH_3$, or odour detection levels over the 10-week trial ($P > 0.10$). Pigs fed the DDGS diets had greater ($P < 0.01$) N and GE intake in all three of the growth phases, but average daily feed intake was not different ($P > 0.10$) among treatments. Dietary DE and ME (kcal/kg) were not different ($P > 0.10$) between the two experimental diets. Percentage of nitrogen retention did not differ between dietary treatments, but feeding DDGS tended to increase N intake and excretion ($P < 0.10$) during all three phases. Percentage of phosphorus retention was not different ($P > 0.10$) between dietary treatments. These results suggest that feeding 20% DDGS has no effect on $H_2S$, $NH_3$, and odour levels over a 10-week manure storage period compared to feeding maize-soyabean meal diets. Feeding DDGS not only increases GE intake and improves phosphorus utilisation during late finishing phases, but also increases N excretion. When diets containing DDGS are formulated on an available phosphorus basis using the available phosphorus value obtained by Whitney *et al.* [38], one would expect the phosphorus excretion in pig manure to be reduced.

## 5. Effect of feeding DDGS on gut health of growing pigs

Whitney *et al.* [44] conducted two experiments to determine if including DDGS in the diet of young growing pigs reduces the incidence or severity of clinical signs, faecal shedding, intestinal lesions, and/or cellular infection indicating porcine proliferative enteropathy (ileitis) after challenge with *Lawsonia intracellularis*. In the first experiment, 80 pigs were weaned at 17 days of age and were randomly allotted (blocked by sex and weight) to one of four treatment groups. A negative control group was unchallenged and fed a control maize-soyabean meal diet. The remaining 3 groups were inoculated orally with $1.5 \times 10^9$ *L. intracellularis* per pig after a 4-week dietary adaptation period, and were fed either a control maize-soyabean meal diet, or a similar diet containing 10 or 20% DDGS. On day 21 post-challenge, all pigs were euthanised and the intestinal mucosa was examined for the presence of lesions. Ileal tissue samples were analysed to determine the presence and proliferation of *L. intracellularis*. Challenging pigs reduced ADFI, ADG, and G/F by 25, 55, and 40%, respectively, during the 3-week post-challenge period. Dietary treatment did not affect growth performance. Gross lesions were observed in 63% of challenged pigs compared with 0% in the negative control group. Including DDGS in the diet did not positively affect lesion prevalence and length, proliferation of *L. intracellularis*, or severity of lesions ($P > 0.10$). In the second experiment, 100 pigs were managed similar to the first experiment, except the *L. intracellularis* dosage rate for challenging pigs was reduced by 50%. Treatment groups consisted of a negative control group and 4 treatments in a 2 × 2 factorial arrangement testing the effect of 10% dietary DDGS inclusion and/or antimicrobial regimen. The antimicrobial regimen consisted of providing 30 mg BMD®/kg diet (supplied continuously in the diet), with chlortetracycline (Aureomycin®) pulsed at 500 mg $kg^{-1}$ from 3 days prior to 11 days post-challenge. Feeding diets containing 10% DDGS reduced ileum and colon lesion length and prevalence ($P < 0.05$), and reduced the severity of lesions in the ileum ($P < 0.05$) and colon ($P < 0.10$) compared to other challenged pigs. Pigs fed the antimicrobial regimen reduced prevalence and severity of lesions in the jejunum ($P < 0.05$), and tended to have reduced total tract lesion length ($P = 0.11$). The combination of DDGS and antimicrobial resulted in no differences ($P > 0.10$) in length, severity, or prevalence of lesions, but faecal shedding of *L. intracellularis* was reduced on day 14 post-challenge ($P < 0.05$). The proportion of intestinal cells infected with *L. intracellularis* was reduced when DDGS ($P = 0.05$) or antimicrobials ($P = 0.10$) were fed. In conclusion, it appears that the dietary inclusion of DDGS may aid the young growing pig in resisting a moderate ileitis challenge similar to a US-approved antimicrobial regimen, but under more severe challenges, DDGS may not be effective.

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