Chapter 12

Sulfur Concerns and Benefits in DDGS

Introduction

Sulfur (S) is an essential mineral for animals and serves many important biological functions in the animal's body. However, when excess S is present in ruminant diets, neurological problems can occur. When feed and water containing high levels of S (greater than 0.40% of diet DM) are fed to ruminants, a condition called polioencephalomalacia (PEM) can occur. Polioencephalomalcia is caused by necrosis of the cerebrocortical region of the brain of cattle, sheep, and goats. When S is consumed by ruminants, it is reduced to hydrogen sulfide by ruminal bacteria. Hydrogen sulfide is toxic and accumulation in the rumen is thought to be the cause of these toxic effects. Ruminants are more vulnerable to PEM when their diets are abruptly changed from a primarily forage diet to a primarily grain diet. This causes a dramatic shift in rumen microbial populations that produce thiaminase, resulting in a thiamin deficiency. Sulfur also appears to have a significant role and interaction with thiaminase production to cause this condition, but the mechanism is not well understood. In addition, excess dietary S can interfere with copper absorption and metabolism. As a result, when high dietary levels of S are fed for an extended period of time, dietary copper levels should also be increased (Boyles, 2007). This condition does not occur in non-ruminant animals (pigs, poultry, fish).

In contrast, feeding diets containing high sulfur DDGS may be beneficial in avoiding metabolic oxidation imbalance in swine. Recent research conducted at the University of Minnesota (Song et al., 2012) showed that high sulfur content in corn DDGS protects against oxidized lipids in DDGS by increasing sulfur-containing antioxidants in nursery pigs.

Managing Sulfur Content in Ruminant Diets When Feeding DDGS

The Beef Cattle NRC (1996) indicates that the maximum tolerable level for S in feedlot diets is 0.40% (DM basis). Vanness et al. (2009) summarized the incidence of PEM from University of Nebraska corn co-product feeding experiments and showed that the PEM incidence rate increases as total dietary S content increases from 0.40% to more than 0.56% in diets containing 6 to 8% forage (**Table 1**). High S diets (> 0.50%) that are low in effective fiber (< 4%) and high in readily fermentable starch (> 30%) are most likely to cause PEM (Drewnoski et al., 2011). For example, Vanness et al. (2009) reported that cattle consuming a distillers grains diet containing 0.47% S with no forage had a PEM incidence rate of 48%, but cattle consuming a diet containing a similar concentration of S with 6 to 8% forage had a PEM incidence rate of < 1%. Research conducted at the University of Nebraska and Iowa State University has shown that the risk for sulfur toxicity may be less when the forage levels in the diets are greater than 6 to 8% (Drewnoski et al. 2011). If 15% forage (DM basis) is included in the diet, total dietary S concentrations can be increased to 0.5%, which is equivalent to an increase of 10 to 15% distillers grains in the diet, without causing PEM. By increasing the forage content of the diet, rumen pH will not be reduced, and therefore, not favor the formation of hydrogen sulfide and allow the concentration of hydrogen sulfide to increase in the rumen. It appears that feeding management strategies that minimize the risk of acidosis, such as minimizing feed intake variation, increased feeding frequency, and the use of ionophores, may also reduce the risk of PEM.

Table 1. Incidence of PEM from University of Nebraska corn co-product feeding experiments.

Dietary S	PEM cases/total head	PEM incidence rate
0.40 to 0.46%	3/2147	0.14%
.47 to 0.56%	3/566	0.35%
>0.56%	6/99	0.56%

Vanness et al. (2009)

Table 2 shows examples of the impact of adding different dietary levels of DDGS, containing different levels of sulfur, to beef cattle diets comprised of corn and corn silage on final diet sulfur levels assuming low sulfate levels in drinking water. These data show that at high dietary inclusion rates (40% of DM intake) and sulfur levels in DDGS greater than 0.80%, total dietary sulfur levels would exceed the 0.40% considered to be the maximum level for causing PEM. If DDGS is going to be fed to cattle, the sulfur content should be determined and considered with the feeding level and sulfur contributions from other dietary ingredients and water to ensure that total dietary sulfur content does not exceed 0.40%.

Table 2. Effect of sulfur content of DDGS and dietary inclusion rate (DM basis) on total dietary sulfur content in corn-corn silage based diets for beef cattle.[1]

DDGS inclusion rate, % DM	0.60% S in DDGS	0.80% S in DDGS	1.0% S in DDGS
20	0.21	0.25	0.29
30	0.27	0.33	0.37
40	0.33	0.41	0.49

[1] Boyles, 2007.

Sulfur levels can be highly variable among DDGS sources and can range from 0.31 to 1.93% (average 0.69%) on a DM basis (www.ddgs.umn.edu). Sulfuric acid is commonly added during the dry grind ethanol production process to keep pH at desired levels for optimal yeast propagation and fermentation to convert starch to ethanol, and is also used for cleaning because of its lower cost relative to other acids. According to AAFCO Official Publication 2004, p 386, sulfuric acid is generally recognized as safe according to U.S. Code of Federal Regulation (21 CFR 582) and is listed as an approved food additive (21 CFR 573). In addition, corn naturally contains about 0.12% sulfur, and is concentrated by a factor of 3, like all other nutrients when corn is used to produce ethanol and DDGS. Yeast also contain about 3.9 g/kg sulfur and naturally create sulfites during fermentation. Based on the significant variability in S content within and among DDGS sources, it is important to determine the S content of the source being fed and monitor load to load variation. This allows nutritionists and feed formulators the ability to determine an adequate safety margin during feed formulation to manage this variability. The potential range of dietary S content, at various DDGS dietary inclusion rates and S content, assuming within plant variation of 10% is shown in **Table 3**.

In addition to the S content of the feedstuffs, drinking water may also be a significant source of total dietary S intake in certain geographic regions. If the S content of drinking water provided to cattle is unknown, it should be tested for sulfate content and considered when determining dietary inclusion rates of DDGS and other ingredients. Cattle water consumption also varies by geographic region and is largely influenced by ambient temperature. The additional dietary S intake obtained from drinking water at various ambient temperatures and water sulfate concentrations are shown in **Table 4**.

Table 3. Range of dietary S[1] based on typical within plant variation of S content in DDGS (DM basis).

S content expected in DDGS, %	Diet S with 30% DDGS, %	Diet S with 40% DDGS, %	Diet S with 50% DDGS, %	Diet S with 60% DDGS, %
0.6	0.32-0.34	0.36-0.38	0.40-0.43	**0.44-0.48**
0.7	0.35-0.37	0.40-0.43	**0.45-0.49**	0.50-0.54
0.8	0.38-0.40	0.44-0.47	0.50-0.54	0.56-0.61
0.9	0.41-0.44	**0.48-0.52**	0.55-0.60	0.62-0.67
1.0	**0.44-0.47**	0.52-0.56	0.60-0.65	0.69-0.74

[1]Assumes no sulfur obtained from drinking water and a maximum of 10% variation of DDGS sulfur content.
Adapted from Drewnoski et al. (2011).

Table 4. Additional dietary S intake (%) from drinking water at various ambient temperatures and water sulfate concentrations[1].

Water sulfate. ppm	5° C	21° C	32° C
200	0.02	0.03	0.05
400	0.04	0.05	0.10
600	0.06	0.08	0.14
800	0.09	0.11	0.19
1000	0.11	0.13	0.24

[1]Percentage of S to add to the ration to determine total dietary S intake.
Adapted from Drewnoski et al. (2011).

Feedlot cattle appear to be most susceptible to S toxicity during the first 30 days on a finishing diet when consuming high S water or high concentrations of S in feed. This increased vulnerability to S toxicity from feeding a high concentrate, high S diet appears to be caused by a dramatic increase in rumen hydrogen sulfide concentrations which results from an increase in sulfate reducing bacteria and a decrease in rumen pH. Since sulfate-reducing bacteria utilize lactate to convert S to sulfide, the increased availability of lactate during this early finishing period may increase their metabolism and produce more hydrogen sulfide. However, hydrogen sulfide concentrations decrease later in the finishing period due to the establishment of bacteria that use lactate and compete with sulfate-reducing bacteria. Therefore, by delaying the feeding of diets with high inclusion rates of DDGS until after the rumen microbes have adapted to a high concentrate diet (approximately 30 days) may also reduce the risk of PEM.

Feeding DDGS with High Sulfur Content to Swine

The maximum tolerable concentration of dietary S in cattle diets is suggested to be 0.40% of DM (NRC, 1996), but the tolerance for S in diets fed to pigs has not been determined. As a result, Kim et al. (2012) conducted 4 experiments to determine if high concentrations of S in DDGS-containing diets negatively affect feed preference and growth performance of weanling and growing-finishing pigs. Based on the results from these 4 experiments, the authors concluded that dietary S concentration does not negatively affect feed preference, feed intake, or growth performance of weanling or growing-finishing pigs fed corn, soybean meal, and DDGS diets.

Oxidative damage of lipids in feed negatively affect pig health and growth performance (Miller and Brzezlnska-Slebodzlnska, 1993; Pfalzgraf et al., 1995). Lipid peroxidation occurs during the production of corn DDGS. Corn oil is typically present at a concentration of approximately 10% in DDGS, and contains high levels of polyunsaturated fatty acids (PUFA), particularly linoleic acid, which are vulnerable to lipid peroxidation (NRC, 1998). Increased drying time and temperature used by some ethanol plants can accelerate lipid peroxidation in the production of DDGS. Furthermore, the total S content in corn DDGS can exceed 1% due to the addition of sulfuric acid during the ethanol production process, and S content in DDGS is highly variable (0.3 to 0.9%, as-fed basis; Kim et al., 2012). Although sulfur is an essential component in many physiological functions of animals and is incorporated into amino acids, proteins, enzymes and micronutrients (Atmaca, 2004), very little is known about the impact of feeding DDGS containing a high concentration of S on pig health and performance.

It is possible that feeding DDGS containing oxidized lipids to pigs may require supplementation of higher levels of antioxidants (e.g. vitamin E) than currently being fed. For example, supplementation of additional antioxidants improved growth performance in pigs fed diets containing DDGS or oxidized corn oil (Harrell et al., 2010). However, results from other studies have shown that supplementation of antioxidants had no effect on growth performance in animals under a dietary oxidative stress challenge (Wang et al., 1997b; Anjum et al., 2002; Fernández-Dueñas, 2009).

Recently, Song et al. (2012) conducted a study to evaluate the effects of feeding DDGS with a high content of oxidized lipids on pig growth performance and metabolic oxidation status, and to determine if any of the negative effects could be overcome by increasing the dietary level of vitamin E. Total S content was higher in DDGS diets than corn-soybean meal control diets (0.39 vs. 0.19%, respectively). Dietary inclusion of 30% DDGS improved apparent total tract digestibility of S (86.8 vs. 84.6%) and S retained compared to feeding corn-soybean meal diets. Although pigs were fed highly oxidized DDGS in this study, serum TBARS were similar between DDGS and the control treatments, and there was no interaction between DDGS and dietary vitamin E concentration in serum TBARS. Serum α-tocopherol concentrations were higher in pigs fed DDGS diets compared with those fed control diets when α-tocopheryl acetate (vitamin E) was not provided or provided at NRC level (1.61 vs. 0.69 μg/mL, respectively). Pigs fed DDGS diets had higher serum concentrations of S-containing amino acids, particularly methionine and taurine, compared with those fed control diets. Liver glutathione concentration was higher in pigs fed DDGS diets than corn-soybean meal diets (56.3 vs. 41.8 nmol/g, respectively). Dietary inclusion of DDGS and vitamin E increased serum enzyme activity of glutathione peroxidase. The elevated concentrations of S-containing antioxidants (methionine, taurine, and glutathione) *in vivo* may protect pigs against oxidative stress when feeding highly oxidized DDGS. Therefore, increasing levels of vitamin E in diets may not be necessary to protect pigs against metabolic oxidative stress when feeding high S and high oxidized DDGS.

Conclusions

Feeding strategies that increase forage intake, reduce variability in feed intake, and stabilize rumen pH will reduce the risk of S toxicity. Providing 15% roughage in the finishing diet after 30 days on a high concentrate diet will allow feeding diets containing up to 0.50% S without the risk of S toxicity. Determining S content variability in DDGS from load to load will allow establishment of acceptable safety margins for use in formulating diets. Water sulfate content and consumption must also be considered when managing total S intake of feedlot cattle. Feeding 30% DDGS diets containing highly oxidized lipid and high sulfur (0.95%) increases sulfur-containing antioxidants and prevents metabolic oxidative stress in young pigs.

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