CHAPTER 12

Benefits and Concerns of Sulfur in DDGS

Introduction

SULFUR (S) IS AN ESSENTIAL MINERAL FOR ANIMALS and serves many important biological functions in the animal's body. The average sulfur content in DDGS is about 0.65 to 0.70 percent, but can exceed 1 percent in some samples (**Table1**), which limits DDGS use in ruminant diets. Sulfuric acid is commonly added during the dry grind ethanol production process to keep pH at desired levels for optimal yeast propagation and fermentation for efficient conversion of starch to ethanol. Sulfuric acid is also used for cleaning because of its lower cost relative to other acids. According to AAFCO Official Publication 2004, page 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 percent sulfur, and is concentrated by a factor of three, like all other nutrients when corn is used to produce ethanol and DDGS. Yeast also contains about 3.9 g/kg sulfur and they naturally create sulfites during fermentation. Based on the significant variability in sulfur content within and among DDGS sources, it is important to determine the sulfur content of the source being fed and monitor variation among lots or batches. Knowing the variation in sulfur content allows nutritionists and feed formulators the ability to provide an adequate safety margin during feed formulation to manage this variability.

However, when excess sulfur is present in ruminant diets, neurological problems can occur. When feed and water containing high levels of sulfur (greater than 0.40 percent of diet dry matter) are fed to ruminants, a condition called polioencephalomalacia (PEM) can occur. PCM is caused by necrosis of the cerebrocortical region of the brain of cattle, sheep, and goats. When sulfur 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 sulfur can interfere with copper absorption and metabolism. As a result, when high dietary levels of sulfur 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 to ruminants, feeding diets containing high-sulfur DDGS may be beneficial in avoiding metabolic stress in swine. Recent research conducted at the University of Minnesota (Song et al., 2013) showed that high sulfur content in corn DDGS protects against peroxidized 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 the maximum tolerable level for sulfur in feedlot diets is 0.40 percent (dry matter 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 sulfur content increases from 0.40 percent to more than 0.56 percent in diets containing six to eight percent forage (**Table 2**). High-sulfur diets (greater than 0.50 percent) that are low in effective fiber (less than 4 percent) and high in readily fermentable starch (greater than 30 percent) are most likely to cause PEM (Drewnoski et al., 2011). For example, Vanness et al. (2009) reported that cattle consuming a DDGS diet containing 0.47 percent sulfur with no forage had a PEM incidence rate of 48 percent, but cattle consuming a diet containing a similar concentration of sulfur with six to eight percent forage had a PEM incidence rate of less than 1 percent. Research conducted at the University of Nebraska and Iowa State University has shown that the risk for sulfur toxicity may be less when the

Table 1. Summary of studies that determined sulfur content (percent dry matter) in DDGS (adapted from Kim et al., 2012)

Reference	No. samples	Mean	SD	Minimum	Maximum
Kim et al., 2012	35	0.65	0.19	0.33	1.04
Kerr et al., 2008	19	0.69	0.23	0.38	1.35
Shurson, 2009	49	0.69	0.26	0.31	1.93

forage levels in the diets are greater than six to eight percent (Drewnoski et al. 2011). If 15 percent forage (dry matter basis) is included in the diet, total dietary sulfur concentrations can be increased to 0.5 percent, which is equivalent to an increase of 10 to 15 percent DDGS 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 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 3 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 dietary sulfur content, assuming low sulfate levels in drinking water. These data show that at high dietary inclusion rates (40 percent of dry matter intake) and high-sulfur levels in DDGS (greater than 0.80 percent), total dietary sulfur levels would exceed the 0.40 percent considered to be the maximum level for causing PEM. The potential range of dietary sulfur content, at various DDGS dietary inclusion rates and sulfur content, assuming within plant variation of 10 percent is shown in **Table 4**. Therefore, when DDGS is fed to cattle, the sulfur content should be determined, and used along with the dietary inclusion rate, as well as sulfur contributions from other dietary ingredients and water, to ensure total dietary sulfur content does not exceed 0.40 percent.

In addition to the sulfur content of the feedstuffs, drinking water may also be a significant source of total dietary sulfur intake in certain geographic regions. If the sulfur content of drinking water provided to cattle is unknown, it should be tested for sulfate content and considered when determining dietary maximum diet 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 sulfur intake obtained from drinking water at various ambient temperatures and water sulfate concentrations are shown in **Table 5**.

Table 2. Incidence of PEM from University of Nebraska corn co-product feeding experiments (adapted from Vanness et al., 2009)

PEM incidence rate	Dietary S	PEM cases/total head
0.14 percent	0.40 to 0.46 percent	3 of 2147
0.35 percent	to 0.56 percent	3 of 566
0.56 percent	greater than 0.56 percent	6 of 99

Table 3. Effect of sulfur content of DDGS and dietary inclusion rate (dry matter basis) on total dietary sulfur content in corn-corn silage based diets for beef cattle (adapted from Boyles, 2007)

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

Table 4. Range of dietary sulfur[1] based on typical within plant variation of sulfur content in DDGS (dry matter basis; adapted from Drewnoski et al., 2011)

S content expected in DDGS %	Diet S with 30 % DDGS %	Diet S with 40 % DDGS %	Diet S with 50 % DDGS %	Diet S with 60 p% 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 percent variation of DDGS sulfur content.

Table 5. Additional dietary S intake (percent) from drinking water at various ambient temperatures and water sulfate concentrations[1] (adapted from Drewnoski et al., 2011)

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.

Feedlot cattle appear to be most susceptible to sulfur toxicity during the first 30 days on a finishing diet when consuming high-sulfate water or high concentrations of sulfur in feed. This increased susceptibility to sulfur toxicity from feeding a high concentrate, high sulfur 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. Because sulfate-reducing bacteria in the rumen use lactate to convert sulfur to sulfide, the increased availability of lactate during this early finishing period may increase microbial 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 these microbes compete with sulfate-reducing bacteria. Therefore, 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 reduce the risk of PEM.

Feeding DDGS with High Sulfur Content to Swine

While the maximum tolerable concentration of dietary sulfur in cattle diets is fairly well established, is has not been determined for monogastric species. Sulfur is an essential component in many physiological functions of animals and is incorporated into amino acids, proteins, enzymes and micronutrients (Atmaca, 2004), but very little was known about the impact of feeding high-sulfur diets, and diets containing DDGS with a high concentration of sulfur on pig health and growth performance until recently. Kerr et al. (2011) conducted a study to evaluate the effects of dietary inorganic sulfur content on growth performance, intestinal inflammation, fecal composition and the presence of sulfate-reducing bacteria. Results from this study showed pigs can tolerate relatively high concentrations of dietary sulfur without negatively affecting growth performance, but feeding high-sulfur diets alters intestinal inflammatory mediators and intestinal bacteria.

Kim et al. (2012) conducted four experiments to determine if high concentrations of sulfur in DDGS-containing diets had negative effects on feed preference and growth performance of weanling and growing-finishing pigs. Based on the results from these four experiments, the authors concluded dietary sulfur concentration does not have adverse effects on feed preference, feed intake or growth performance of weanling or growing-finishing pigs fed corn, soybean meal and DDGS diets. In a subsequent study, Kim et al. (2012) showed that feeding 20 percent DDGS diets containing up to 0.38 percent sulfur had no detrimental effects on feed preference, feed intake or growth performance of nursery or growing-finishing pigs. An additional study conducted by Kim et al. (2014) showed that feeding 30 percent DDGS with high-sulfur content had no negative effects on growth performance of growing finishing pigs, and did not affect carcass characteristics or tissue sulfur concentrations.

In fact, elevated sulfur content in DDGS appears to have beneficial effects to counteract any potential negative effects of feeding highly peroxidized DDGS sources. Peroxidative damage of lipids in feed has been shown to negatively affect pig health and growth performance (Miller and Brzezlnska-Slebodzinska, 1993; Pfalzgraf et al., 1995; Hung et al., 2017). Lipid peroxidation occurs during the production of corn DDGS. Song and Shurson (2013) analyzed corn oil extracted from 31 corn DDGS sources and showed peroxidation of oil in DDGS can be 20 to 25 times greater than found in oil from corn grain. Corn oil contains high concentrations of polyunsaturated fatty acids (PUFA), particularly linoleic acid, which is highly susceptible to lipid peroxidation (Shurson et al., 2015). Therefore, it is possible that feeding DDGS containing oxidized lipids to pigs may require supplementation of higher levels of antioxidants (e.g. vitamin E) than they are 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).

To determine if feeding the most peroxidized DDGS source identified in a previous study (Song and Shurson, 2013), had detrimental effects on growth performance of nursery pigs, Song et al. (2013) fed corn-soybean meal or 30 percent peroxidized DDGS (PV = 84.1 mEq.kg oil; TBARS = 5.2 ng MDA/kg oil; 0.95 percent sulfur) diets containing one of three levels of vitamin E (none, 11 IU/kg, or 110 IU/kg). Serum α-tocopherol concentrations were greater in pigs fed DDGS diets containing no supplemental vitamin E, or 11 IU/kg of supplemental vitamin E compared to those fed the control diet. Furthermore, pigs fed the DDGS diets had greater serum concentrations of sulfur-containing amino acids (Met and taurine), compared with pigs fed the control diet. Liver glutathione concentration was also greater in pigs fed the DDGS diets compared with those fed the control diet, and enzyme activity of glutathione peroxidase was also increased. These results suggest the increased concentrations of sulfur-containing antioxidants (Met, taurine, glutathione) may protect pigs against oxidative stress when feeding highly peroxidized DDGS sources to pigs, and feeding elevated concentrations of vitamin E in diets may not be necessary to protect pigs against oxidative stress when feeding a high-sulfur and highly peroxidized DDGS source.

To further evaluate the effects of feeding a highly peroxidized DDGS to sows and their offspring through the nursery period, Hanson et al. (2015) fed corn-soybean meal control diet during gestation and lactation, or 40 percent DDGS gestation diets and 20 percent DDGS lactation diets to sows. At weaning, pigs from these litters were fed 0 percent, or 30 percent peroxidized DDGS (PV = 84.1 mEq.kg oil; TBARS = 5.2 ng MDA/kg oil; 0.95 percent sulfur) with supplemental vitamin E at five times the NRC (2012) requirement. Pigs from sows fed DDGS had lower serum vitamin E concentrations during preweaning and post weaning compared to pigs from sows fed the control diet. During the nursery period, pigs fed the DDGS diets had greater ADFI than pigs fed the control diet, but ADG was not different among treatments. Furthermore, feeding the 30 percent peroxidized DDGS diets during the nursery period increased serum vitamin E, but had no effect on serum TBARS or glutathione peroxidase. Perhaps the most interesting finding of this study was the serum concentrations of sulfur amino acids was about 40 to 50 percent greater compared with pigs fed the control diets, which was likely due to the greater sulfur amino acid intake of pigs fed the DDGS diets. Therefore, the antioxidant properties of sulfur amino acids appeared to be sufficient to overcome the potential negative effects on growth performance and oxidative status from feeding peroxidized DDGS, and likely spared vitamin E so the additional supplementation of vitamin E was not needed.

In summary, feeding diets containing up to 0.38 percent sulfur from DDGS and inorganic sources has no detrimental effects on growth performance, carcass characteristics and tissue sulfur concentration of pigs. Furthermore, there is some evidence DDGS containing high concentrations of sulfur (0.95 percent), when added at 30 percent to diets for weaned pigs, results in increased antioxidant protection provided by sulfur-containing amino acids.

Conclusions

Feeding strategies that increase forage intake, reduce variability in feed intake and stabilize rumen pH will reduce the risk of sulfur toxicity when feeding high-sulfur diets to ruminants. Providing 15 percent roughage in the finishing diet after 30 days on a high-concentrate diet will allow feeding diets containing up to 0.50 percent sulfur without the risk of sulfur toxicity. Determining the variability in DDGS sulfur content from various lots or batches received at a feed mill or feedlot will allow for determining acceptable safety margins for use in formulating ruminant diets. Water sulfate content and consumption must also be considered when managing total sulfur intake of feedlot cattle. In contrast, feeding 30 percent DDGS diets containing highly oxidized lipid and high sulfur (0.95 percent) has been shown to increase sulfur-containing antioxidants and prevent metabolic oxidative stress in young pigs. Feeding diets containing up to 0.38 percent sulfur from DDGS and inorganic sources has no detrimental effects on growth performance, carcass characteristics and tissue sulfur concentration of pigs

References

Anjum, M.I., M.Z. Alam and I.H. Mirga. 2002. Effect of nonoxidized and oxidized soybean oil supplemented with two levels of antioxidant on broiler performance. Asian-Aust. J. Anim. Sci. 15:713-720.

Atmaca, G. 2004. Antioxidant effects of sulfur-containing amino acids. Yonsei Med. J. 45: 776–788.

Boyles, S. 2007. Distillers Grains with Solubles. OSU Extension Beef Team, BEEF Cattle Letter 551.

Drewnoski, M., S. Hansen, D. Loy, and S. Hoyer. 2011. How much distillers grains can I include in my feedlot diet? Iowa Beef Center, Iowa State University Extension, IBC 46. 3 pp.

Fernández-Dueñas, D.M. 2009. Impact of oxidized corn oil and synthetic antioxidant on swine performance, antioxidant status of tissues, pork quality and shelf life evaluation. Ph.D. dissertation thesis, Urbana, IL.

Hanson, A.R., L. Wang, L.J. Johnston, S.K. Baidoo, J. L. Torrison, C. Chen, and G.C. Shurson. 2015. Effects of feeding peroxidized dried distillers grains with solubles to sows and progeny on growth performance and metabolic oxidative status of nursery pigs. J. Anim. Sci. 93:135-146.

Harrell, R. J., J. Zhao, G. Reznik, D. Macaraeg, T. Wineman, and J. Richards. 2010. Application of a blend of dietary antioxidants in nursery pigs fed either fresh or oxidized corn oil of DDGS. J. Anim. Sci. 88 (Suppl. 3): 97 (Abstr).

Hung, Y.T., A.R. Hanson, G.C. Shurson, and P.E. Urriola. 2017. Peroxidized lipids reduce growth performance of poultry and swine: A meta-analysis. Anim. Feed Sci. Technol. 231:47-58.

Kerr, B.J., T.E. Weber, C.J. Ziemer, C. Spence, M.A. Cotta, and T.R. Whitehead. 2011. Effect of dietary inorganic sulfur level on growth performance, fecal composition, and measures of inflammation and sulfate-reducing bacteria in the intestine of growing pigs. J. Anim. Sci. 89:426-437.

Kerr, B.J., C.J. Ziemer, T.E. Weber, S.L. Trabue, B.L. Bearson, G.C. Shurson, and M.H. Whitney. 2008. Comparative sulfur analysis using thermal combustion or inductively coupled plasma methodology and mineral composition of common livestock feedstuffs. J. Anim. Sci. 86:2377-2384.

Kim, B.G., D.Y. Kil, D.C. Mahan, G.M. Hill, and H.H. Stein. 2014. Effects of dietary sulfur and distillers dried grains with solubles on carcass characteristics, loin quality, and tissue concentrations of sulfur, selenium and copper in growing-finishing pigs. J. Anim. Sci. 92:4486-4493.

Kim, B.G., Y. Zhang, and H.H. Stein. 2012. Sulfur concentration in diets containing corn, soybean meal and distillers dried grains with solubles does not affect feed preference or growth performance of weanling or growing-finishing pigs. J. Anim. Sci. 90:272–281.

Miller, J.K. and E. Brzezinska-Slebodzinska. 1993. Oxidative stress, antioxidants and animal function. J. Dairy Sci. 76:2812–2823.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th revised edition. National Academy Press, Washington, D.C.

Pfalzgraf, A., M. Frigg, and H. Steinhart. 1995. -Tocopherol contents and lipid oxidation in pork muscle and adipose tissue during frozen storage. J. Agric. Food Chem. 43:1339-1342.

Shurson, G.C, B.J. Kerr, and A.R. Hanson. 2015. Evaluating the quality of feed fats and oils and their effects on pig growth performance. J. Anim. Sci. Biotechnol. 6:10.

Shurson, G.C. 2009. Nutrient profiles: Current U.S. data www.ddgs.umn.edu

Song, R. and G.C. Shurson. 2013. Evaluation of lipid peroxidation level in corn dried distillers grains with solubles. J. Anim. Sci. 91:4383-4388.

Song, R., C. Chen, L. Wang, L.J. Johnston, B.J. Kerr, T.E. Weber, and G.C. Shurson. 2013. High-sulfur content in corn dried distillers grains with solubles protects against oxidized lipids by increasing sulfur-containing antioxidants in nursery pigs. J. Anim. Sci. 91:2715-2728.

Vanness, S.J., T.J. Klopfenstein, G.E. Erickson, and K.K. Karges. 2009. Sulfur in Distillers Grains. Nebraska Beef Report, University of Nebraska-Lincoln, p. 79-80.

Wang, S. Y., W. Bottje, P. Maynard, J. Dibner, and W. Shermer. 1997b. Effect of santoquin and oxidized fat on liver and intestinal glutathione in broilers. Poult. Sci. 76:961-967.