CHAPTER 15

Reduced-Oil DDGS in Beef Cattle Diets

Introduction

THE U.S. BEEF CATTLE INDUSTRY has been a major consumer of wet and dried corn distillers co-products for decades. In 2017, the U.S. beef industry was the greatest consumer of distillers co-products amount all animal species, which represent 44 percent of total domestic use. As a result, there has been a significant amount of research conducted to evaluate the feeding value of corn distillers co-products to beef cattle, of which most has focused on optimizing use in finishing feedlot beef cattle where it is used in the greatest quantities. Several excellent research summaries and feeding recommendations were been published 10 or more years ago (Erickson et al., 2005; Tjardes and Wright, 2002; Loy et al., 2005a; Loy et al., 2005b, Klopfenstein et al. (2008)). However, over 140 studies have been published since 2010 and the results of these studies are summarized in this chapter.

Energy, Nutrient Composition and Digestibility of Corn Distillers Co-Products Beef Cattle

Corn DDGS is used as both a high-energy and mid-protein feed ingredient in beef cattle diets. A detailed summary of the averages and ranges of DDGS nutrient composition is provided in **Chapter 4** of this handbook. In the U.S., finishing beef cattle have successfully been fed as much as 40 percent DDGS of ration dry matter as a replacement for corn grain. However, when adding more than 30 percent corn DDGS to the diet for use primarily as an energy source, it provides more protein and phosphorus than required for finishing feedlot cattle.

Energy

The primary carbohydrate fraction in DDGS is NDF (neutral detergent fiber). Much of the NDF in DDGS is obtained from the pericarp (bran) portion of the corn kernel which contains about 69 percent NDF, and is highly (87 percent) and rapidly (6.2 percent per hour) digested (DeHaan et al., 1983). Because of the highly digestible and rapidly fermentable fiber in DDGS, it is frequently used as a high energy and protein source in diets for feedlot finishing cattle.

The corn oil present in DDGS is also a significant contributor to its energy content. Vander Pol et al. (2007) showed the digestibility of corn oil was 70 percent. However, as the level of fatty acid intake increases, fatty acid digestion decreases (Plascencia et al., 2003), which likely explains the decline in feeding value of DDGS when fed at high (greater than 30 percent) levels of the diet.

Initial studies indicated that the NE_{gain} of corn DDGS for beef cattle was 21 percent greater than the NE value of dry-rolled corn (Ham et al., 1994). A subsequent review by Tjardes and Wright (2002) indicated corn DDGS contains 2.16 to 2.21 Mcal/kg of NE_m and 1.50 to 1.54 Mcal/kg of NE_g among sources. In fact, many ruminant nutritionists prefer using corn DDGS instead of corn grain for finishing feedlot cattle because it contains 118 to 130 percent of the energy value of corn, and due to its low starch and readily fermentable fiber content, feeding high amounts reduces the risk of rumen acidosis compared with feeding dry-rolled corn (Ahern et al., 2011).

Unfortunately, there are limited data on the energy content of reduced-oil DDGS for beef cattle. Bremer (2014) determined the energy value of reduced-oil (7.2 percent crude fat) and high-oil (12.0 percent crude fat) modified wet DDGS with solubles when fed at 20 or 40 percent of dry matter intake to growing calves and showed no difference in energy content between the reduced-oil and high-oil modified wet DDGS with solubles sources. They estimated the energy value of these two DDGS sources was about 124 percent of the energy value of corn grain. However, when these sources of modified DDGS with solubles were fed to finishing cattle, the reduced-oil DDGS source had about 89 percent of the feeding value of high-oil DDGS, but feeding the reduced-oil modified wet distillers source improved gain:feed with increasing diet inclusion rates.

DDGS reduces acidosis

Feeding diets containing DDGS reduces acidosis in feedlot cattle fed high-grain diets. Subacute acidosis is often a problem when finishing cattle are fed high-grain diets because corn grain contains a high amount of rapidly fermentable starch. However, the starch content in DDGS is low (two to 5 percent), while the fiber, protein and fat content are relatively high allowing the amount of forage in the diet to be reduced when feeding diets containing more than 20 percent DDGS of dry matter intake. Furthermore, low-quality forages can be used effectively in diets that contain greater than 20 percent DDGS because of its high protein content (Klopfenstein et al., 2008).

Protein

Corn DDGS is relatively high in protein (27 to 30 percent) content, and historically has also been used as a protein supplement in feedlot cattle diets (Klopfenstein et al., 2008). Most of the protein in corn DDGS is zein, which has a high rumen escape value (Little et al., 1968), and about 40 percent of zein is degraded in the rumen (McDonald, 1954). Although rumen bypass protein has been shown to be quite variable among DDGS sources (Aines et al., 1987), protein in DDGS has 1.8 times greater protein value than protein in soybean meal.

Corn DDGS is high in rumen undegradable protein (RUP). Acid detergent insoluble nitrogen (ADIN) can be used to determine the extent of protein damage of DDGS, and once this ADIN value is determined in the laboratory, it can be multiplied by a factor of 6.25 to estimate the amount of crude protein in DDGS that is unavailable and can be compared to the actual crude protein value to determine the extent of protein damage. The proportion of bypass protein (RUP) in DDGS is approximately 60 to 70 percent compared with 30 percent for soybean meal. However, Erickson et al. (2005) indicated the high bypass protein value of DDGS is due to the innate characteristics of the protein rather than drying or moisture content, and does not appear to be influenced by ADIN since protein efficiency (kg gain/kg supplemental protein) appears to stay the same, or increase as the amount of ADIN in DDGS increases.

Limited studies have been conducted to determine RUP protein content of DDGS in beef cattle. Castillo-Lopez (2013) determined the RUP content, as a percentage of crude protein, was about 63 percent. Feeding DDGS tended to decrease duodenal bacterial protein supply, had no effect on duodenal protozoa crude protein, and provide a small amount of yeast crude protein.

Li et al. (2012) compared wheat, corn, wheat DDGS, high-oil (11.5 percent crude fat) corn DDGS and reduced-oil (4.5 percent crude fat) DDGS on *in situ* and *in vitro* degradability of crude protein and amino acids. They estimated the true digestibility of dietary protein was 98.5, 96.5, 94.3, 93.5 and 88.9 percent for wheat, corn, wheat DDGS, high-oil corn DDGS and reduced-oil corn DDGS, respectively. These researchers concluded ruminal degradation of crude protein in DDGS was less than in the original grain, and lower for reduced-oil corn DDGS than high-oil corn DDGS, but not different between wheat DDGS and corn DDGS. Ruminal degradation of essential amino acids was greatest for wheat DDGS, followed by high-oil corn DDGS and reduced-oil corn DDGS. Although the protein quality and essential amino acids in RUP was slightly less than the original grains, all of these sources are excellent sources of RUP. In a subsequent study, Li et al. (2013) showed that wheat DDGS and reduced-oil (4.5 percent crude fat) corn DDGS, when supplemented in backgrounding cattle diets, provided greater amounts of crude protein and amino acids in the small intestine, compared with feeding canola meal and high-oil DDGS when diets were formulated on an isonitogenous basis.

Urea

When cattle diets contain high amounts of rapidly fermentable carbohydrates (e.g. corn grain) and a high proportion of the dietary crude protein is derived from corn, a deficit in degradable protein intake may occur. Ceconi et al. (2015) conducted two experiments to evaluate the effect of increasing intake of degradable protein and the addition of urea on feedlot cattle growth performance, carcass characteristics, rumen fermentation, total tract digestibility and purine derivatives-to-creatinine index. Results from this study showed that due to limited degradable protein intake from feeding dry-rolled corn and high-moisture corn diets containing 20 percent DDGS, urea supplementation was necessary to improve ruminal fermentation, feed digestibility and growth performance.

Phosphorus

Corn DDGS is low in calcium but relatively high in phosphorus (P) and sulfur content. Depending upon the feeding level, adding distiller's grains to the diet may allow complete removal of other supplemental phosphorus sources from the mineral mixture previously fed. Due to the high levels of DDGS fed, beef cattle feedlot diets contain excess phosphorus relative to their requirement. This results in excess phosphorus being excreted in manure, and must be considered when developing manure management plans to prevent unwanted environmental pollution. Due to the low calcium level of DDGS, supplemental calcium sources (e.g. ground limestone or alfalfa) must be added to the diet to maintain a calcium to phosphorus ratio between 1.2:1 to no more than 7:1 to avoid reductions in animal performance and urinary calculi (Tjardes and Wright, 2002).

Geisert et al. (2010) fed diets containing brewers grits to provide low phosphorus (0.12 percent P), medium phosphorus (0.27 percent) and high phosphorus (0.42 percent P) with supplemental monosodium phosphate, dry-rolled corn and 30 percent DDGS, to determine phosphorus digestibility and excretion. Results from this study showed that adding 30 percent DDGS to the diet results in relatively high total phosphorus content and intake, and it is about 50 percent digestible (**Table 1**). However, the amount of digestible phosphorus in DDGS exceeds the phosphorus requirement for finishing cattle and results in a significant amount of total phosphorus excretion (about 54 percent of intake). The phosphorus requirement for finishing cattle is less than the phosphorus content of typical U.S. beef cattle feedlot diets (0.30 to 0.50 percent) and NRC (2001) estimates. Therefore, the addition of supplemental phosphorus to a typical corn-based or DDGS-based diet is unnecessary because the phosphorus requirement for maximum growth performance is less than 0.17 percent of diet dry matter. By eliminating excess phosphorus provided by mineral supplements from

Table 1. Phosphorus intake, apparent digestibility and excretion from beef steers fed different amounts and source of dietary phosphorus (adapted from Geisert et al. 2010)

	Low P	Medium P	High P	Dry-rolled corn	DDGS
Diet phosphorus %	0.12	0.27	0.42	0.30	0.36
Dry matter intake, kg/day	8.86	10.54	9.76	9.57	9.48
Dry matter digestibility %	71.9	69.6	72.5	75.7	68.5
P intake, g/day	11.0[a]	28.0[b]	41.3[d]	28.9[b]	34.0[c]
Apparent phosphorus digestibility %	11.3[a]	48.9[b]	39.0[b]	58.6[b]	51.5[b]
Fecal phosphorus excreted, g/day	9.3[a]	14.2[a]	26.0[b]	12.1[a]	15.9[a]
Urine phosphorus excreted, g/day	0.4[a]	2.2[b]	1.9[b]	2.0[b]	2.3[b]
Total phosphorus excreted, g/day	9.7[a]	16.3[ab]	27.9[c]	14.0[ab]	18.2[b]
% excreted in urine as percent of total phosphorus excreted	3.5	14.2	9.9	14.3	12.4

[a,b,c,d]Means within row without the same superscript are different (P less than 0.10).

feedlot cattle diets, the amount of phosphorus excretion in manure will be reduced to minimize the risk of negative environmental consequences.

High diet inclusion rates of DDGS increases nitrogen and phosphorus excretion in manure

When DDGS is used as an energy source and added to the diet at levels greater than 15 to 20 percent, excess protein and phosphorus are fed. The excess protein is used for energy that occurs through deamination of amino acids and results in urea excretion. Vander Pol et al. (2005) showed when finishing cattle are fed diets containing 10 or 20 percent DDGS of diet dry matter, there is no benefit for supplementing diets with urea, suggesting nitrogen recycling was occurring. However, Erickson et al. (2005) suggested NRC (2001) guidelines should be followed for degradable intake protein supplementation when formulating diets containing less than 20 percent DDGS. Feeding excess phosphorus provided by DDGS in feedlot cattle diets does not appear to have any negative effects on performance or carcass traits if adequate calcium is supplemented to the diets to maintain an acceptable calcium to phosphorus ratio.

Sulfur

High levels of sulfur in DDGS can be a concern for beef feedlot cattle (Lonergan et al. 2001), and **Chapter 14** provides a more detailed summary of managing sulfur intake in ruminants. Ethanol plants use sulfuric acid to adjust pH during ethanol and DDGS production. As a result, sulfur content of DDGS can be highly variable and range from 0.6 to 1.0 percent. Adequate dietary sulfur is required by microorganisms in the rumen, but too much sulfur in the diet can cause polioencephalomalcia, reduce dry matter intake, ADG and liver copper levels. Felix et al. (2012a) indicated that when greater than 30 percent DDGS is included in the ruminant diet, dry matter intake, rumen pH and fiber digestibility in beef cattle may be reduced when it comprises the majority of the diet dry matter). An increase in rumen pH to 6.35 can increase dry matter intake and improve ruminal digestibility of nutrients (Leventini et al., 1990). Therefore, adding alkaline supplements to high-DDGS diets may be effective in increasing pH and improving nutrient digestibility and several studies have been conducted to evaluate the effects of thiamine, copper, NaOH and CaO in high sulfur diets containing DDGS.

Neville et al. (2012) evaluated the effects of feeding 20, 40 or 60 percent DDGS diets and corn processing method (high-moisture corn vs. dry-rolled corn) on growth performance, incidence of polioencephalomalacia and concentrations of hydrogen sulfide gas in feedlot steers. Diets contained 0.6 to 0.9 percent sulfur, and were supplemented with thiamine to provide 150 mg/animal/day. Carcass-adjusted final body weight decreased linearly with increasing concentrations of DDGS in the diet, but carcass adjusted gain:feed was not affected. Hot carcass weight and backfat were reduced when feeding increasing levels of DDGS resulting in decreased yield grade. Hydrogen sulfide gas increased with increasing concentration of DDGS in the diet but there were no confirmed cases of polioencephalomalacia. Corn processing method did not affect growth performance, incidence of polioencephalomalacia, or hydrogen sulfide gas concentrations in the rumen. These results, as well as those reported by Neville et al. (2010) and Schauer et al. (2008) have consistently demonstrated sulfur from DDGS can be fed in excess of the maximum tolerable level in both lambs and steers fed high concentrate diets. It is possible the maximum tolerable level of sulfur reported in NRC (2005) needs to be re-evaluated.

Copper supplementation in DDGS-based diets may be effective in reducing rumen hydrogen sulfide production and prevent sulfur toxicity when high amounts of DDGS containing high sulfur content is fed. In the rumen, copper and sulfur can precipitate and form copper sulfides, which reduce the availability of both copper and sulfur to the animal (McDowell, 2003). The maximum tolerable level of copper in beef cattle diets has been reported to be 100 mg/kg diet dry matter (McDowell, 2003). Therefore, Felix et al. (2012a) evaluated the effects of supplementing 60 percent DDGS diets with 0, 100 or 200 mg Cu/kg diet dry matter on growth performance, carcass characteristics and rumen sulfur metabolism in growing beef heifers and steers. Results showed that although supplemental copper improved feed efficiency of cattle consuming 60 percent DDGS diets, and had no effect on ADG or carcass characteristics, the effects of copper supplementation on rumen sulfur metabolism were minimal, even when supplemented at twice the recommended maximum tolerable limit for beef cattle.

Because reduced rumen pH interferes with fiber fermentation, and DDGS has a relatively high-fiber content and relatively low pH, there have been several research studies to determine the effects on using alkaline treatments or supplements to increase rumen pH and fiber digestibility. Felix et al. (2012b) showed cattle fed 25 to 60 percent DDGS diets treated with 2 percent NaOH prior to feeding, increased *in situ* NDF disappearance compared with cattle fed DDGS diets with no NaOH treatment. Treating DDGS with 2 percent NaOH may increase rumen pH and decrease hydrogen sulfide concentrations to reduce the risk of polioencephalomalacia, and adding NaOH was effective in neutralizing the acidity from sulfuric acid in DDGS. However excess Na in ruminant diets can reduce feed intake (Croom et al., 1982), and the optimal inclusion of alkaline treatment to reduce the acid effects of DDGS-based diets to improve growth performance has not been determined. Therefore, Frietas et al. (2016) conducted a study to determine the optimal diet inclusion rate of NaOH in 50 percent DDGS-based diets to improve growth performance, carcass characteristics and feed intake patterns of feedlot steers. However, due to the low pH (5.5) of the DDGS source fed in this study, there was no effect of adding up to 1.5 percent NaOH to DDGS diets on growth performance or carcass characteristics.

Increased feeding value and growth performance may be achieved when feeding more than 30 percent DDGS diets by adding calcium oxide because treating DDGS with alkaline agents before feeding improves nutrient digestibility (Felix et al., 2012b). Schroeder et al. (2014) conducted a study to determine the effects of feeding 50 percent DDGS diets with or without supplemental calcium oxide on growth performance, carcass characteristics, diet digestibility, pattern of feed intake and meal distribution. Results from this study showed steers fed calcium oxide-treated DDGS had decreased dry matter intake, but had no effect on ADG, which resulted in an improvement in gain:feed compared with steers not fed calcium-oxide. Steers fed the calcium oxide-treated DDGS ate a similar number of meals but the amount consumed in each meal was less than those fed DDGS without CaO treatment. Although CaO treatment of DDGS improved feed efficiency, it had no effect of dry matter or NDF digestibility. In contrast, Nuñez et al. (2014) evaluated the addition of calcium oxide to 60 percent DDGS diets fed to feedlot steers on ruminal fermentation, diet digestibility, growth performance and carcass characteristics of feedlot steers. Their results showed that adding up to 1.6 percent CaO was effective in improving growth performance fiber digestibility, volatile fatty acid production, amino acid utilization, metabolic acid-base balance and carcass dressing percentage, while minimizing rumen pH variation in feedlot cattle fed 60 percent DDGS diets.

If more than 0.4 percent sulfur from feed (dry matter basis) and water is consumed, polioencephalomalacia in cattle can occur. Furthermore, sulfur interferes with copper absorption and metabolism, which is further reduced in the presence of molybdenum. Therefore, in geographic regions where high sulfur levels are found in forages and water, the level of DDGS that can be added may need to be reduced (Tjardes and Wright, 2002). Drewnoski et al. (2014) indicated the risk of sulfur toxicity can be minimized when feeding high dietary inclusion rates of DDGS with high-sulfur content to cattle by providing at least 7 to 8 percent NDF from a forage source in diets containing more than 0.4 percent total sulfur. **Table 2** can be used as a guide to determine maximum diet inclusion rates of DDGS with variable sulfur content for finishing feedlot cattle to avoid the risk of sulfur toxicity and the occurrence of polioencephalomalacia.

Feeding DDGS to Finishing Cattle

Feeding wet and DDGS to beef cattle is perhaps the most extensively researched among all animal species. As one of many examples, Buckner et al. (2007) conducted a study to evaluate the effects of feeding increasing levels of DDGS to finishing steers on growth performance and carcass characteristics (**Table 3**). Results from this study showed no effect of increasing levels of DDGS on dry matter intake, twelth rib fat depth, loin muscle area and marbling score, but there was a quadratic effect in ADG and hot carcass weight, and a quadratic trend for gain:feed. Furthermore, the feeding value of DDGS is greater than corn at all of the diet inclusion rates evaluated, but declines with increasing dietary inclusion rates (**Table 3**). Klopfenstein et al. (2008) used the Buckner et al. (2007) data, along with results from four other experiments in their meta-analysis. Their results also showed a quadratic response to ADG when increasing levels of DDGS were fed, but observed a cubic response in gain:feed. Results from the meta-analysis showed maximum ADG is achieved when including 20 to 30 percent DDGS in the diet, and maximum gain:feed is achieved by feeding 10 to 20 percent DDGS diets for finishing cattle.

Table 2. Range in dietary sulfur[1] in corn-based beef cattle finishing rations assuming 10 percent variation from among loads of DDGS (adapted from Drewnoski et al., 2014)

	DDGS inclusion rate %				
	20	30	40	50	60
Sulfur in DDGS %	Dietary S %				
0.3	0.16 – 0.17	0.18 – 0.18	0.20 – 0.21	0.22 – 0.23	0.23 – 0.25
0.4	0.18 – 0.19	0.21 – 0.22	0.24 – 0.25	0.27 – 0.29	0.29 – 0.32
0.5	0.20 – 0.21	0.24 – 0.27	0.28 – 0.30	0.32 – 0.34	0.35 – 0.38
0.6	0.22 – 0.24	0.26 – 0.30	0.32 – 0.34	0.37 – 0.40	0.41 – 0.45
0.7	0.24 – 0.26	0.28 – 0.33	0.36 – 0.39	0.42 – 0.45	0.47 – 0.51
0.8	0.26 – 0.28	0.33 – 0.35	0.40 – 0.43	0.52 – 0.56	0.53 – 0.58
0.9	0.28 – 0.30	0.36 – 0.38	0.44 – 0.47	0.52 – 0.56	0.59 – 0.65
1.0	0.30 – 0.32	0.39 – 0.41	0.48 – 0.52	0.57 – 0.62	0.65 – 0.71

[1]Assumes no sulfur is obtained from drinking water and that other diet ingredients contain 0.13 percent sulfur.

Table 3. Growth performance and carcass characteristics of finishing beef steers fed increasing levels of DDGS in the diet (adapted from Buckner et al., 2007)

Response criteria	0% DDGS	10% DDGS	20% DDGS	30% DDGS	40% DDGS
Dry matter intake, kg/d	9.25	9.47	9.52	9.71	9.47
ADG, kg	1.50	1.61	1.68	1.62	1.59
Gain:Feed	0.162	0.171	0.177	0.168	0.168
Feeding value[1]	100	156	146	112	109
Hot carcass wt., kg	351	362	370	364	359
12th rib fat, cm	1.42	1.37	1.50	1.40	1.47
Loin muscle area, cm^2	80.0	80.6	82.6	81.3	81.3
Marbling score[2]	533	537	559	527	525

[1]Value relative to corn calculated by difference in Gain:Feed divided by DDGS dietary inclusion rate.

[2]Marbling score of 400 = slight0, 500 = small0

Another recent example of the positive benefits of feeding high dietary inclusion rates (up to 40 percent) of DDGS to finishing beef cattle, was conducted by Swanson et al. (2014). In this study, researchers fed diets containing 20 or 40 percent DDGS with coarse or finely ground corn to yearling steers to determine the effects on growth performance and carcass traits. Final body weight and ADG were not affected by DDGS inclusion rate or corn particle size, but dry matter intake decreased and gain:feed increased with increasing DDGS inclusion rate (**Table 4**). Carcass traits were not affected by DDGS inclusion rate or dry-rolled corn particle size. These results show that up to 40 percent DDGS can be fed to finishing cattle to improve ADG and gain:feed without affecting carcass quality.

Several studies (n = 28) have been conducted since the meta-analysis conducted by Klopfenstein et al. (2008), and a summary of these studies is shown in **Table 5**. Unfortunately, the crude fat content of the DDGS sources used were not reported for the majority of these studies, but is indicated in the summary if this information was available. Studies by Frietas et al. (2017), Engle et al. (2016), Rodenhuis et al. (2016), Nuñez et al. (2015), Gigax et al. (2011) and Leupp et al. (2009) reported using reduced-oil wet or DDGS in finishing beef cattle studies. In the study by Gigax et al. (2011), diets containing dry-rolled and high moisture corn with 35 percent dry matter of wet DDGS with solubles (WDGS) containing reduced-oil (6.7 percent) or high-oil (12.9 percent) crude fat were fed to finishing steers. Cattle fed the high-oil WDGS

Table 4. Effects of feeding fine and coarse dry-rolled corn and 20 or 40 percent DDGS diets on growth performance and carcass characteristics of finishing cattle (adapted from Swanson et al., 2014)

	Dry-rolled corn processing			
	Coarse (2.68 mm)		Fine (1.46 mm)	
Measure	**20% DDGS**	**40% DDGS**	**20% DDGS**	**40% DDGS**
Initial body weight, kg	345	345	343	345
Final body weight, kg	606	607	600	603
ADG, kg/day	2.06	2.05	2.01	2.03
Dry matter intake, kg/day[1]	12.1	11.0	11.6	11.0
Dry matter intake % of body weight/day[1]	2.55	2.31	2.47	2.31
Gain:Feed[1]	0.169	0.185	0.169	0.178
Hot carcass weight, kg	361	369	360	360
12th rib fat thickness, cm	1.06	1.37	1.27	1.28
Loin muscle area, cm^2	82.2	82.0	81.3	83.3
Marbling score[2]	543	538	533	530

[1]Effect of DDGS inclusion rate (P less than 0.001)

[2]Marbling score = 500 for modest and 600 for moderate marbling

had increased ADG, final body weight and hot carcass weight compared with steers fed the corn or reduced-oil WDGS diets, but steers fed the reduced-oil WDGS diet had similar dry matter intake, ADG and gain:feed as cattle fed the corn control diet. These results suggest that feeding 35 percent reduced-oil WDGS provides at least equal growth performance and carcass composition as feeding dry-rolled and high moisture corn diets to finishing steers.

It is interesting to note many of these recent studies evaluated very high (50 to 70 percent) diet inclusion rates of DDGS, and depending on the diet formulation and feeding conditions, a few reported good growth performance and carcass characteristics. Furthermore, several studies routinely used 20 to 25 percent DDGS diets as control diets, which suggests there is a high degree of confidence among nutritionists that acceptable growth performance and carcass characteristics are consistently achieved when feeding diets containing up to 25 percent DDGS to feedlot cattle. Therefore, there is no reason why similar and relatively high diet inclusion rates of DDGS should not be used in other countries.

Table 5. Summary of 28 published studies evaluating growth performance and carcass characteristic responses[1] of finishing beef cattle fed various types of DDGS diets since 2009

Growth phase, initial BW	DDGS inclusion; crude fat content	Feeding conditions	Growth Responses	Carcass Responses	Reference
Finishing cattle					
Steers, 211-261 kg	50 percent; 8.8 percent crude fat	Diets contained 20 percent corn silage, 20 percent dry-rolled corn, and 50 percent DDGS with 0, 0.5, 1.0, or 1.5 percent NaOH	No effects of NaOH supplementation on final BW, ADG, and gain:feed	No effects of NaOH level on HCW, LM are, carcass yield, backfat thickness, or marbling	Frietas et al., 2017
Steers, 310 kg	26 percent grower and finisher; 5.8 or 9.6 percent crude fat	Grower diets contained 19 percent grass hay, 22 percent corn silage, 30 percent corn or barley, 3 percent supplement; Finisher diets contained 20 percent corn silage, 51 percent corn or barley, 3 percent supplement	No differences in ADG, DMI, and Gain:Feed	No difference in carcass dressing percentage, HCW, YG, LM area, marbling score, and backfat	Engle et al., 2016

Table 5. Summary of 28 published studies evaluating growth performance and carcass characteristic responses[1] of finishing beef cattle fed various types of DDGS diets since 2009

Growth phase, initial BW	DDGS inclusion; crude fat content	Feeding conditions	Growth Responses	Carcass Responses	Reference
Steers, 436 kg	20, 40, or 60 percent DDGS; 10 percent crude fat	Diets contained increasing amounts of DDGS to replace dry-rolled corn and 300 mg ferric Fe/kg from ferric ammonium citrate (FAC) and contained 0.28, 0.41, 0.56 percent sulfur	Final BW linearly decreased with increasing DDGS, but tended to be greater with FAC than without FAC when feeding 60 percent DDGS; there was a quadratic effect on DMI and feeding 60 percent DDGS decreased DMI	Increasing diet DDGS decreased HCW and LM area, but marbling scores improved when feeding 20 and 40 percent DDGS with FAC compared with the same DDGS inclusion without FAC	Pogge et al., 2016
Steers, 428 kg	Not reported; 4-5 percent (Low) or 7-9 percent (Med) crude fat	Corn or barley diets with Low or Med DDGS	No effect of DDGS oil content on final BW and ADG, and Gain:Feed was greater from barley-based diets	No effect of DDGS oil content or grain type on carcass traits	Rodenhuis et al., 2016
Year 1 – Steers, 396 kg Year 2 – Steers, 436 kg	25 percent; crude fat content not reported	Two-year study using stocker diets containing 75 percent corn silage and 25 percent corn gluten feed, or 25 percent DDGS, or 10 percent soybean meal and 15 percent ground corn, placed on tall fescue pasture for 30 days, and fed the same as the stocker period in during the 100 day finisher period	Steers fed DDGS diet had greater ADG and Gain:Feed than those fed corn-soybean meal	No differences in carcass characteristics due to diet except steers fed corn gluten feed had greater LM area and marbling scores; steaks from steers fed DDGS were more tender based on sensory panel	Stelzleni et al., 2016
Steers, 428 kg	20 percent; crude fat content not reported	0, 0.4, or 0.6 percent urea added to 12 percent high moisture corn, 20 percent DDGS, 10 percent ryegrass haylage and dry-rolled corn diets	0.6 percent urea diet increased carcass adjusted ADG and Gain:Feed, but final BW and DMI were similar among treatments	Carcass characteristics were similar among dietary treatments	Ceconi et al., 2015
Steers and heifers, 351 kg	0 or 60 percent DDGS; 6.9 percent crude fat	Corn-based diet fed for 126 days and 60 percent DDGS diet fed for 70 days followed by a corn-based diet until day 126	Feeding the corn-based diet increased ADG, DMI, and Gain:Feed during the first 70 days but feeding DDGS increased ADG, DMI, and Gain:Feed from 71 to 126 days resulting in no differences in ADG and Gain:Feed for the overall feeding period	-	Nuñez et al., 2015
Steers, 450 kg	0, 20, 30 percent; crude fat content not reported	Barley grain and barley silage diets contained increasing DDGS as a replacement for barley grain	Feeding 20 percent DDGS had no effect of growth performance but feeding 30 percent DDGS decreased Gain:Feed	Feeding 20 percent DDGS had no effect on carcass traits and feeding 30 percent DDGS increased desirable fatty acids in beef	He et al., 2014

Table 5. Summary of 28 published studies evaluating growth performance and carcass characteristic responses[1] of finishing beef cattle fed various types of DDGS diets since 2009

Growth phase, initial BW	DDGS inclusion; crude fat content	Feeding conditions	Growth Responses	Carcass Responses	Reference
Steers, 287 kg	0 percent, 0.5 percent, or 1 percent of BW daily of DDGS; 11.1 percent crude fat	84-day feeding period where steers were fed medium quality grass/legume hay ad libitum and increasing amounts of supplemental DDGS	Quadratic response to ADG and Gain:Feed where the increase in Gain:Feed was less when feeding one percent DDGS	Increasing DDGS increased LM area, back fat thickness, and rump fat thickness	Islas et al., 2014
Steers, 359 kg	32 percent DDGS and 7 percent condensed distillers solubles; crude fat content not reported	84-day feeding period of six diets containing 3.5 to 11.4 percent NDF from bromegrass hay with 0.46 percent dietary sulfur from DDGS and condensed distillers solubles	No effect of NDF level on final BW, ADG, and Gain:Feed, but DMI intake increased linearly.	-	Morine et al., 2014
Steers, 355 kg	60 percent; crude fat content not reported	60 percent DDGS, 20 percent corn silage, 13-14 percent ground corn, 4 percent supplement, and 0 to 2.5 percent CaO	Increased CaO linearly increased ADG and Gain:Feed, but linearly decreased DMI	Carcass yield linearly increased up to 1.6 percent CaO but did not affect other carcass characteristics	Nuñez et al., 2014
Steers, 368 kg	0, 16.7, 33.3, 50 percent wet (WDGS) or DDGS (dry matter basis); crude fat content not reported	Diets contained 10 percent chopped alfalfa/grass haylage and increasing levels of WDGS or DDGS to replace whole corn grain	No effect of WDGS or DDGS or inclusion rate on final BW and ADG; liver abscess score decreased linearly with increasing DDGS level	No effect of diet on carcass yield, HCW, marbling score, lean yield, or lean color	Salim et al., 2014
Steers, 336 kg	50 percent DDGS or modified wet DDGS with solubles (MWDGS); crude fat content not reported	DDGS or MWDGS replaced alfalfa hay and corn husklage, with or without 1.2 percent CaO	Feeding CaO treated DDGS decreased dry matter intake, had no effect on ADG, and improved Gain:Feed compared with those not fed CaO	-	Schroeder et al., 2014
Steers, 345 kg	20 or 40 percent; crude fat content not reported	Diets contained coarse- or fine-rolled corn and 20 or 40 percent DDGS	Corn processing or DDGS had no effect on final BW and ADG, but DMI decreased and Gain:Feed increased with increasing DDGS level	No effect of increasing DDGS inclusion rate on carcass characteristics or quality	Swanson et al., 2014
Steers, 268 kg	1 percent of BW; crude fat content not reported	Winter grazing dormant tall grass pasture for 121 days with supplements of 1 kg/day of a cottonseed meal, 1 percent of BW of corn-soybean meal or soybean hulls and meal, or DDGS	Steers supplemented with corn-soybean meal had greater ADG than those fed soybean hulls and meal or DDGS	Energy supplementation increased mesenteric fat and YG but had no effect on 12th-rib fat thickness or marbling score	Sharman et al., 2013
Steers, 335 kg	0, 25, 40, 70 percent dry matter of modified wet DDGS with solubles (MWDGS); 10.4 percent crude fat	Diets contained 15 percent corn silage and increasing MWDGS to replace shelled corn and soybean meal	No differences in MWDGS inclusion rate on ADG or final BW; feeding 0 percent or 70 percent MWDGS resulted in the lower DMI but Gain:Feed was greatest when feeding 70 percent MWDGS	Steers fed 70 percent MWDGS had smaller rib eye areas and quality grades declined with increasing MWDGS	Veracini et al., 2013

Table 5. Summary of 28 published studies evaluating growth performance and carcass characteristic responses[1] of finishing beef cattle fed various types of DDGS diets since 2009

Growth phase, initial BW	DDGS inclusion; crude fat content	Feeding conditions	Growth Responses	Carcass Responses	Reference
Steers from grazing winter wheat pasture, 363 to 403 kg	35 percent; 12.2 percent crude fat	Two-year study with two groups of steers fed DDGS diets replacing steam flaked corn, urea, and cottonseed meal	No difference in BW gain but feeding dry rolled-corn improved Gain:Feed compared with control and DDGS diets	No difference in LM area, YG, marbling score but feeding steam flaked corn increased dressing percentage, 12th rib fat thickness, and empty body fat	Buttrey et al., 2012
Steer calves, 297 kg	22.5 percent wheat or corn DDGS; crude fat content not reported	Dry-rolled barley (71 percent), 5 percent barley silage, and 2 percent supplement with wheat or corn DDGS	Corn DDGS increased ADG and Gain:Feed compared with wheat DDGS; ADG and DMI was greater for corn DDGS than control diet	Corn DDGS had a fewer carcasses with YG 1 and more with YG grade 2 and 3 compared with steers fed the control diet	Hallewell et al., 2012
Steers, 336 kg	20, 40, or 60 percent; crude fat content not reported	Diets contained 20, 40, or 60 percent DDGS with dry-rolled corn or high moisture corn in 5 percent alfalfa hay and 10 percent corn silage diets	No cases of PEM occurred; carcass-adjusted final BW and ADG decreased quadratically, but Gain:Feed was not affected by feeding increasing DDGS diets; corn processing method did not affect growth performance	Increasing diet DDGS level decreased HCW, fat depth, and YG	Neville et al., 2012
Steers, 252 kg	65 percent; crude fat content not reported	Diets contained 65 percent DDGS or corn limited fed to predicted gain of either 0.9 or 1.4 kg BW/day during growing and finishing phases	Overall ADG, DMI, and Gain:Feed were greater when feeding corn during grower but not during finisher compared with DDGS	During the growing phase, feeding DDGS to achieve greater ADG increased marbling but feeding corn to increase ADG decreased marbling	Felix et al., 2011
Steers, 403 kg	0 or 35 percent wet DDGS with solubles (WDGS); 6.7 or 12.9 percent crude fat	Control diet contained 85 percent dry-rolled and high moisture corn with 10 percent sorghum silage and 35 percent reduced-oil or high-oil WDGS were added to replace corn and urea	Feeding high-oil WDGS increased ADG and final BW compared with feeding reduced-oil WDGS or corn diets; no difference in DMI, ADG, and Gain:Feed of cattle fed reduced-oil WDGS and corn diets	Feeding high-oil WDGS increased HCW compared with feeding corn or reduced-oil WDGS diets, but no effect on other carcass traits	Gigax et al., 2011
Steers, 306 kg	24.5 percent; crude fat content not reported	Stocker diet contained 75 percent corn silage with 25 percent DDGS, corn gluten feed, or soybean meal and fed for 84 days and fed same protein supplements for 100 days of finishing	-	No effect of supplement on carcass yield and quality, but steaks from steers fed DDGS or corn gluten feed were more tender than those fed soybean meal	Segers et al., 2011
Yearling steers, 406 kg	30 percent; 12.0 percent crude fat	Steam-flaked con or dry-rolled corn diets containing 30 percent DDGS with moderate S (0.42 percent S) or high S (0.65 percent S achieved by adding H_2SO_4)	High sulfur diets decreased dry matter intake and ADG but had no effect on Gain:Feed	High sulfur diets decreased HCW and YG but did not affect dressing percentage, liver abcesses, 12th-rib fat thickness, LM area, or quality grades	Uwituze et al., 2011

Table 5. Summary of 28 published studies evaluating growth performance and carcass characteristic responses[1] of finishing beef cattle fed various types of DDGS diets since 2009					
Growth phase, initial BW	**DDGS inclusion; crude fat content**	**Feeding conditions**	**Growth Responses**	**Carcass Responses**	**Reference**
Steers, 349 kg	20 or 40 percent DDGS or 20 or 40 percent wet DDGS with solubles (WDGS); crude fat content not reported	DDGS or WDGS replaced all of the soybean meal and a portion of cracked corn	-	Feeding WDGS or DDGS increased carcass fat thickness, YG, and resulted in a lower percentage of YG 1 and 2, and α-tocopherol content in gound beef than steers fed the control diet; feeding WDGS and DDGS had no effect on conjugated linoleic acid content of meat, but increased PUFA content making it more susceptible to peroxidation	Koger et al., 2010
Heifers, 353 kg	0 or 25 percent: 10.1 percent crude fat	Diets contained steam-flaked corn and 11 percent corn silage with or without 25 percent DDGS or steam-flaked corn and 6 percent alfalfa hay with or without 25 percent DDGS	Feeding DDGS had no effect on ADG, DMI, or Gain:Feed; liver abscesses were greater when DDGS was not included in the diet	No differences in HCW, carcass yield, fat thickness, quality or YG among diets	Uwituze et al, 2010
Steers, 257 kg	0, 10.5, or 17.5 percent in growing diet; 0, 11.4, or 18.3 percent in finishing diet; crude fat content was not reported	Diets contained increasing amount of DDGS to replace dry-rolled barley for an 84-day grower period and a 112-day finisher feeding period	No difference in initial and final BW, but DMI decreased and ADG and Gain:Feed increased in the growing period by feeding DDGS diets; DDGS decreased DMI during the finishing period but tended to increase Gain:Feed with no difference in DDGS inclusion rate	Feeding DDGS increased marbling score and YG, but tended to decrease rib eye area; feeding the high DDGS diet increased backfat thickness	Eun, J.-S. et al., 2009
Steers, 443 kg	25 or 50 percent; 13.9 percent crude fat content	Corn-based diets containing 25, or 50 percent DDGS, 25 percent DDGS diets containing 12 percent corn gluten feed, or 2.4 or 2.8 percent supplemental soybean oil	Steers fed the 25 percent DDGS diet had greater ADG and Gain:Feed than those fed 50 percent DDGS diets with elevated protein or elevated protein and fat	Steers fed the 25 percent DDGS diet had greater HCW, marbling scores, and quality grades, but there were no differences in carcass yield, 12th-rib fat depth LM area, YG, shear force or meat peroxidation among treatments	Gunn et al., 2009
Steers, 296 kg	30 percent; 9.7 percent crude fat	Growing and finishing diets contained combinations of 0 or 30 percent DDGS	Growing and finishing period showed no differences in DMI, ADG, and Gain:Feed from feeding DDGS	DDGS inclusion rate had no effect on LM area, 12th-rib fat thickness, YG, marbling, and tenderness but steaks from steers fed 30 percent DDGS in the finisher or throughout were juicier and more flavorful	Leupp et al., 2009

[1]Abbreviations used: ADG = average daily gain, BW = body weight, DMI = dry matter intake, Gain:Feed = gain to feed ratio, HCW = hot carcass weight, LM = loin muscle, YG = yield grade

Feeding DDGS to Growing or Stocker Cattle

Less research has been conducted related to feeding corn DDGS to other ages of cattle. However, DDGS is an excellent feed ingredient that can be effectively used to supplement energy and protein in the diet when cattle are fed low-quality forages. When DDGS is added to diets containing forages low in phosphorus, the phosphorus in DDGS will be of significant value. Five studies have been conducted with growing or stocker cattle to evaluate feeding up to 60 percent DDGS diets **(Table 6**). In general, feeding DDGS diets resulted in either no effects or improved growth performance and carcass traits when DDGS was fed.

Feeding DDGS to Beef Calves

Three studies have been conducted with beef calves to evaluate feeding up to 60 percent DDGS diets (**Table 7**). In general, feeding DDGS diets resulted in increased growth performance and improvements in various carcass traits when DDGS was fed.

Feeding DDGS to Pastur-Grazing Cattle

An additional three studies have been conducted with pasture grazing to evaluate the benefits of supplementing DDGS on growth and subsequent carcass responses (**Table 8**). In general, feeding DDGS supplements improved growth performance and carcass traits.

Table 6. Summary of five published studies evaluating growth performance and carcass characteristic responses[1] of growing or stocker beef cattle fed various types of DDGS diets since 2009

Growth phase, initial BW	DDGS inclusion; crude fat content	Feeding conditions	Growth Responses	Carcass Responses	Reference
Growing/stocker cattle					
Year 1 - Steers, 305 kg Year 2 – Steers and heifers, 301 kg	25 percent; 10.9 percent crude fat	Two-year study of two groups fed corn silage-based diets (75 percent dry matter) with 25 percent corn gluten feed, 25 percent DDGS, or 25 percent soybean meal and ground ear corn	Steers fed DDGS and corn-soybean meal diets had greater ADG, DMI was less and Gain:Feed was greatest for those fed DDGS; cost per kg gain was lowest for steers fed DDGS	No difference in predicted carcass traits among dietary treatments using ultrasound	Segers et al., 2013
Steers, 198 to 208 kg	Dry-rolled corn or DDGS supplement fed at 0.5 percent of BW; crude fat content was 11.6 percent	Two-year study of two groups of steers grazing winter wheat pasture with or without supplemental dry-rolled corn or DDGS	ADG increased 8 percent by feeding DDG supplement compared to no supplement or dry-rolled corn	-	Buttrey et al., 2012
Steers and heifers, 238 kg	60 percent; crude fat content not reported	0, 100, or 200 mg Cu/kg dry matter was added to 60 percent DDGS diets with 10 percent long stem grass hay, 15 percent pelleted soy hulls, and 15 percent supplement	No effect of Cu supplementation on ADG but Gain:Feed linearly increased with increased Cu supplementation	No effect of Cu supplementation on HCW, LM area, YG, backfat or marbling score	Felix et al., 2012a
Steers, 277 kg	60 percent; crude fat content not reported	0 or 10 percent haylage, with 0 or 33 mg monensin/kg diet, and 60 percent DDGS, 10 percent corn silage, 15 percent supplement, and 5 or 15 percent corn	ADG increased in 10 percent haylage diets and was further increased by adding monensin, but DMI and Gain:Feed decreased with added haylage	-	Felix and Loerch, 2011
Holstein bulls, 246 kg	0, 0.8, or 1.6 kg/day of DDGS; crude fat content not reported	Corn silage was provided ad libitum with 1.1 kg soybean meal, 1.5 kg rapeseed meal, 1.6 kg DDGS, or 0.8 kg rapeseed meal and 0.8 kg DDGS daily	ADG was lower when feeding DDGS compared with DDGS plus rapeseed meal but not different than other treatments; there were no differences in Gain:Feed among diets	No effect on final BW, carcass yield, and internal fat	Meyer et al., 2010

[1]Abbreviations used: ADG = average daily gain, BW = body weight, DMI = dry matter intake, Gain:Feed = gain to feed ratio, HCW = hot carcass weight, LM = loin muscle, YG = yield grade

Table 7. Summary of three published studies evaluating growth performance and carcass characteristic responses[1] of growing or stocker beef cattle fed various types of DDGS diets since 2009					
Growth phase, initial BW	**DDGS inclusion; crude fat content**	**Feeding conditions**	**Growth Responses**	**Carcass Responses**	**Reference**
Calves					
Heifers and steers, 156 kg	11 to 34; crude fat content not reported	Four diets providing high fat with high or low crude protein, and low fat with high or low crude protein to replace corn	High protein diets increased ADG, and calves fed the corn diet had decreased DMI but increased Gain:Feed compared with DDGS diets	High fat diets increased carcass 12th rib fat and marbling score, and high protein diets decreased marbling score. No differences in HCW, LM area, or YG	Segers et al., 2014
Holstein steers, 112 kg	0, 10, 20, or 30 percent; crude fat content not reported	Diets contained increasing levels of DDGS to replace steam-flaked corn and fed for 305 days	Increasing DDGS levels linearly increased ADG and Gain:Feed responded quadratically during initial 126 day feeding period but during final 179 day period and overall there were no effects on growth performance	HCW was greatest when feeding 20 percent DDGS but no other effects on carcass characteristics were observed among DDGS inclusion rates	Carrasco et al., 2013
Early weaned steers, 200 kg	0, 30, or 60 percent DDGS; crude fat content was 9.8 percent	20 percent corn silage containing 0, 30, or 60 percent DDGS for 99 days then fed a common diet until slaughter	Dietary DDGS inclusion level had no effect on ADG, DMI, or Gain:Feed during growing phase and had no carryover effects on growth performance during the finishing phase	Dressing percentage, HCW, fat thickness responded quadratically to DDGS inclusion rate, there were no effects on marbling, but the ratio of intramuscular fat to subcutaneous fat increased by feeding 30 to 60 percent DDGS and decreased by feeding 0 to 30 percent DDGS	Schoonmaker et al., 2013

[1]Abbreviations used: ADG = average daily gain, BW = body weight, DMI = dry matter intake, Gain:Feed = gain to feed ratio, HCW = hot carcass weight, LM = loin muscle, YG = yield grade

Table 8. Summary of 3 published studies evaluating growth performance and carcass characteristic responses[1] of grazing beef cattle fed various types of DDGS diets since 2009

Growth phase, initial BW	DDGS inclusion; crude fat content	Feeding conditions	Growth Responses	Carcass Responses	Reference
Grazing cattle					
Steers, 204 kg	0, 0.25, or 0.5 percent of BW; 13.3 percent crude fat	Two-year study of steers grazing desert rangeland with shrubs in northern Mexico and fed increasing amounts of DDGS supplement three times weekly	Final BW, ADG, and supplement conversion increased with increasing DDGS supplementation	-	Murillo et al., 2016
Steers, Year 1 = 206 kg Year 2 = 230 kg	DDGS supplemented at 0, 0.2, 0.4, or 0.6 percent of BW; 12.1 percent crude fat	Two-year study with grazing periods of 56 to 58 days on native range during forage growing season and fed increasing levels of DDGS supplementat 0, 0.2, 0.4, or 0.6 percent of BW	ADG increased linearly with increasing level of DDGS supplement	-	Martinez-Pérez et al., 2013
Yearling steers, 321 kg	1 percent of BW during grazing period; 40 percent during finishing period; crude fat content not reported	Bromegrass pasture with supplement containing low S (0.34 percent S from DDGS) or high S (0.47 percent S from DDGS and $NaSO_4$); finisher diets were 48 percent corn, 40 percent DDGS, 8 percent chopped hay	No effect of dietary S on ADG during the pasture period; Increasing diet S decreased ADG during subsequent finishing period but did not affect DMI and Gain:Feed	Feeding high dietary S during the finishing period decreased HCW but had no effect on carcass fat, LM area, yield grade, or marbling score	Richter et al., 2012

[1]Abbreviations used: ADG = average daily gain, BW = body weight, DMI = dry matter intake, Gain:Feed = gain to feed ratio, HCW = hot carcass weight, LM = loin muscle, YG = yield grade

Beef quality

In general, feeding diets containing typical amounts of DDGS (up to 30 percent of dry matter intake) does not change the quality or yield of beef carcasses, and it has no effect on the sensory and eating characteristics of beef (Erickson et al. 2005). An increasing number of studies have evaluated the quality and sensory characteristics of beef from cattle fed wet or DDGS, and results consistently show no negative effects on eating characteristics of beef from cattle fed high dietary levels of DDGS.

Roeber et al. (2005) evaluated color, tenderness and sensory characteristics of beef strip loins from two experiments where wet or dried corn DDGS were fed to Holstein steers at levels up to 50 percent of the ration. There were no differences in tenderness, flavor and juiciness. Similarly, Jenschke et al. (2006) showed finishing beef cattle fed diets containing up to 50 percent wet distiller's grains (dry matter basis) produced steaks similar in tenderness, amount of connective tissue, juiciness or off-flavor intensity. In fact, steaks from cattle fed the 0 and 10 percent wet DDGS with solubles diets were most likely to have an off-flavor compared to steaks from cattle fed the 30 and 50 percent wet DDGS with solubles diets. Gordon et al. (2002) fed diets containing 0, 15, 30, 45, 60 or 75 percent DDGS to finishing heifers during a 153-day finishing trial and observed there was a small, linear improvement in tenderness of steaks from cattle fed increasing amounts of DDGS.

Koger et al. (2010) fed Angus crossbred steers diets containing 20 or 40 percent wet or dry DDGS with solubles to replace all of the soybean meal and some of the cracked corn. Carcasses of steers fed DDGS had greater fat thickness and improved yield grades than steers fed the dry-rolled corn, soybean meal and alfalfa hay control diet. Loin muscle from steers fed DDGS had higher ultimate pH values than loins from steers fed wet DDGS. Ground beef from steers fed DDGS had higher α-tocopherol compared to those fed the control diet, but steers fed 40 percent DDGS produced ground beef with higher TBARS (thiobarbituric acid reactive substances), which is an indicator of lipid peroxidation, on day two of retail display than ground beef from steers fed 20 percent DDGS diets. These researchers concluded steers fed DDGS may need to be marketed earlier than normal to avoid excess external fat, but there are no adverse or beneficial effects on the incidence of "dark cutters" retail display life of ground beef or meat tenderness.

However, beef from cattle fed distillers grains have increased polyunsaturated fatty acids which may be more susceptible to oxidative rancidity.

Leupp et al. (2009) showed no differences in growth performance when steers were fed 0 or 30 percent DDGS in the growing or finishing period. Marbling and tenderness were not affected by diet, but steaks from steers fed DDGS during finishing were juicier and had more flavor. These data suggest DDGS can be included at 30 percent dietary dry matter in the growing or finishing period to partially replace dry-rolled corn with no detrimental effects on performance, carcass characteristics or sensory attributes. However, feeding 30 percent DDGS may negatively affect steak color.

Similarly, Segers et al. (2011) showed the composition and tenderness of longissimus lumborum steaks were unaffected by feeding diets containing 25 percent DDGS or corn gluten feed compared with using soybean meal as a protein supplement from weaning to harvest. However, similar to the effects of steak color observed by Leupp et al. (2009), trained panelists in this study also observed differences in perceived color, but overall color was similar among steaks among the dietary treatment groups. Unlike the study by Koger et al. (2010), there were no differences in TBARS concentration among treatment groups, but steaks from steers fed DDGS became more discolored after nine days of retail display, and contained greater polyunsaturated fatty acid content, which suggests lipid oxidation may occur and reduce the shelf life for fresh meat products from cattle fed DDGS. Results from this study also indicated DDGS and corn gluten feed can be substituted for soybean meal and a portion of corn in beef cattle diets from weaning to slaughter while maintaining meat quality.

Aldai et al. (2010a,b) compared the effects of feeding wheat versus corn DDGS to feedlot cattle on meat quality and showed wheat DDGS had no negative effects on meat quality. In contrast, feeding corn DDGS had some positive effects on meat quality such as improved tenderness and palatability compared to beef from cattle fed the barley control diet.

Impact of feeding DDGS on *E. coli* O157:H7 shedding

In 2007, there was a dramatic increase in interest in identifying and understanding the possible reasons for the increases in *E. coli* O157:H7 in ground beef contamination in the U.S. Because of the exponential increase in ethanol and distiller's grains production during this same time period, there were some suspicions feeding distiller's grains were contributing to this problem. As a result, researchers began conducting studies to determine if there was a relationship between feeding distiller's grains with solubles and the increased incidence of *E. coli* O157:H7 in beef. However, research results from several studies have shown there is no consistent effect of feeding DDGS on *E. coli* O157:H7 shedding in beef cattle. The response to *E. coli* O157:H7 shedding may be affected by DDGS feeding level and other dietary ingredients such as type of corn processing. Currently, there is no scientific evidence suggesting the levels of DDGS being fed is a cause for *E. coli* O157:H7 contamination in ground beef. Refer to **Chapter 18** of this handbook for a more detailed, comprehensive summary of research results related to the potential association of DDGS with the prevalence of fecal shedding of E. coli O157:H7.

Feeding DDGS to Beef Cows

Other potential uses of DDGS include providing it as a creep feed for calves nursing cows, a supplement for grazing cattle and a supplement for low-quality forages and crop residues that might be fed to growing calves, gestating beef cows or developing beef heifers. However, unlike growing-finishing beef cattle, less research has been conducted on feeding DDGS to beef cows. Loy et al. (2005a) published an initial summary of results from including DDGS in beef cow diets, and indicated the best applications for using DDGS are in situations where 1) supplemental protein is needed (especially when feeding low quality forages) to replace corn gluten feed or soybean meal, 2) a low starch, high fiber energy source is needed to replace corn gluten feed or soy hulls and 3) when a source of supplemental fat is needed.

DDGS as a supplemental protein source

Previous research has shown when DDGS was supplemented to provide 0.18 kg of protein/day to beef cows grazing native winter range in Colorado, it compared favorably to alfalfa hay or cull navy beans (Smith et al., 1999). Shike et al. (2004) compared performance effects of feeding corn gluten feed or DDGS as a supplement to ground alfalfa hay to lactating Simmental cows and observed that cows fed DDGS gained more weight, but produced less milk compared to cows fed corn gluten feed. However, there were no differences between cows fed DDGS and those fed corn gluten feed on calf weights and rebreeding performance. In a subsequent study, Loy et al. (2005a) reported that limiting feeding total mixed rations of ground corn stalks supplemented with either DDGS or corn gluten feed to lactating Angus and Simmental cows nursing calves resulted in no differences in milk production and calf weight gains between cows supplemented with DDGS or corn gluten feed.

DDGS as a supplemental energy source

Corn DDGS is an effective energy supplement when fed with low-quality forages. Summer and Trenkle (1998) showed DDGS and corn gluten feed were superior supplements to corn in corn stover diets, but not in high-quality alfalfa diets.

Corn stover (stalks) are low in protein, energy and minerals, but are low in cost and readily available in major corn producing states in the U.S. When low-quality forages (e.g. corn stover) are fed to gestating beef cows in good condition, feeding 1.4 to 2.3 kg of DDGS per day during the last third of gestation will provide adequate protein and energy to meet the cow's requirements (Loy and Miller, 2002). For beef cows fed low quality forage (e.g. corn stalks) in early lactation, supplementing with 2.7 to 3.6 kg of DDGS will meet their protein and energy requirements (Loy and Miller, 2002).

Radunz et al. (2010) evaluated the effects of feeding grass hay, corn or DDGS as late gestation dietary energy sources on pre- and post-partum cow performance. When these energy sources were fed at or above daily requirements, there were no detrimental effects on pre- or post-partum cow performance, and feeding DDGS as a pre-partum dietary energy source reduced daily feed costs during gestation. Dietary energy source affected the partitioning of energy and caused changes in plasma metabolites resulting in heavier birth weights of calves from cows fed DDGS or corn during late gestation compared to those fed grass hay.

DDGS as a supplemental fat source

Supplemental fat may improve reproduction in cow herds experiencing suboptimal pregnancy rates (less than 90 percent). Loy and Miller (2002) indicated that feeding supplements with similar fatty acid profiles to corn oil (found in DDGS) improved pregnancy rates. They also indicated that fat supplementation is most beneficial in feeding situations where protein and/or energy supplementation is necessary.

Engle et al. (2008) evaluated the effects of feeding DDGS compared with soybean hulls, in late gestation heifer diets, on animal and reproductive performance and showed that pre-partum diets containing DDGS, as a source of fat and undegradable intake protein, improved pregnancy rates in well-maintained primiparous beef heifers.

Shike et al. (2009) evaluated the effects of using corn co-products in limit-fed rations on cow performance, lactation, nutrient output and subsequent reproduction. Cows fed DDGS lost 16 kg less body weight and had 0.9 kg/d less milk production, which resulted in calves tending to have lower ADG than for cows fed corn gluten feed. However, in a second experiment, cows were fed 2.3 kg/d of ground cornstalks and isocaloric amounts of corn gluten feed (7.7 kg/d) or DDGS (7.2 kg/d) to meet nutrient requirements. Results from this experiment showed cows fed DDGS tended to lose more weight than those fed corn gluten feed, but there were no differences in milk production or calf ADG. Furthermore, there were no differences in reproductive performance in both experiments, suggesting that DDGS and corn gluten meal can be included up to 75 percent of a limit-fed diet, but the higher fat content of DDGS compared with corn gluten feed did not improve reproduction.

A summary of 13 published studies that have evaluated feeding DDGS supplements to gestating beef cows is shown in **Table 9**, and 4 additional studies with gestating beef heifers is shown in **Table 10**. In general, providing DDGS supplements had either no effect or improved reproductive performance of cows or heifers and subsequent growth, carcass or reproduction effects of progeny.

Table 9. Summary of 13 published studies evaluating beef cow reproductive performance and subsequent growth, carcass or reproductive responses[1] of progeny fed various types of DDGS diets since 2009

Reproductive phase	DDGS inclusion rate and crude fat content	Feeding conditions	Reproductive performance responses	Progeny growth, carcass, or reproductive responses	Reference
Gestating cows					
Fall-calving multiparous cows, 623 kg	0, 2.2, or 8.6 kg/day of a 70 percent DDGS and 30 percent soybean hulls supplement; crude fat content not reported	Two-year study where cows grazed endophyte infected tall fescue/red clover pasture and fed increasing amounts of from 103 days prepartum to two days postpartum	-	No effect on heifer progeny at weaning, breeding, or pregnancy, AI conception rate, pregnancy rate, and calving rate; calf birth weight, percentage of unassisted births, milk production, and calf BW at 73 days of age from heifer progeny were not affected by supplementation	Shoup et al., 2017

Table 9. Summary of 13 published studies evaluating beef cow reproductive performance and subsequent growth, carcass or reproductive responses[1] of progeny fed various types of DDGS diets since 2009

Reproductive phase	DDGS inclusion rate and crude fat content	Feeding conditions	Reproductive performance responses	Progeny growth, carcass, or reproductive responses	Reference
Multiparous cows	0, 2.5, or 4.7 kg DDGS/day; crude fat content not reported	Fed isocaloric silage TMR with or without supplemental DDGS during early lactation	Increasing DDGS supplement increased milk fat and urea content and feeding 2.5 kg DDGS increased milk lactose content; final BW, ADG, age at puberty, and conception rates were not different among treatments for heifer offspring	-	Taylor et al., 2017
First and second parity cows, 520 kg	0 or 0.35 percent of BW daily, every third day, or every sixth day; crude fat content not reported	Grazing corn residues with or without DDGS supplementation	Daily and every third day supplementation increased ADG, and BCS was greater for daily supplementation	-	Gross et al., 2016
Multiparous cows, 674 kg	0.3 percent of BW last third of gestation and eight weeks after calving; crude fat content not reported	10 week late gestation feeding period of corn stover and silage with or without DDGS supplement	No effects on dystocia but cows fed DDGS had heavier calves at birth due to greater blood glucose, and heavier weaning weights; DDGS supplements increased uterine blood but decreased estradiol and progesterone concentrations	-	Kennedy et al., 2016a,b,c
Multiparous cows, 653 kg	0 or 6.9 kg/day DDGS; crude fat content not reported	Cow-calf pairs were fed diets supplemented with DDGS or soybean meal from calving until 129 days postpartum and consisted of either rye hay and DDGS or corn silage, rye hay and soybean meal	No effects of diet on milk production but milk urea nitrogen and fat increased, wihile milk protein decreased by feeding DDGS; timed AI rates increased by feeding DDGS but no effects on pregnancy rate	ADG and BW of calves increased from cows fed DDGS	Shee et al., 2016
Spring-calving multiparous cows, 657 kg	19 or 39 percent modified wet DDGS with solubles (dry matter basis); crude fat content not reported	Diets contained oatlage, corn silage, and modified wet DDGS with solubles providing protein and the requirement or 129 percent of requirement and fed 78 days pre-partum to calving	No effect of diet on cow BW, BCS, milk production, subsequent reproduction, or progeny pre-weaning growth performance	No effect of progeny finishing growth and carcass marbling scores, but feeding the high protein supplement increased carcass twelth rib fat thickness and YG	Wilson et al., 2016a

Table 9. Summary of 13 published studies evaluating beef cow reproductive performance and subsequent growth, carcass or reproductive responses[1] of progeny fed various types of DDGS diets since 2009

Reproductive phase	DDGS inclusion rate and crude fat content	Feeding conditions	Reproductive performance responses	Progeny growth, carcass, or reproductive responses	Reference
Spring-calving multiparous cows, 688 kg	0 or 7 percent DDGS in post-calving diets, and 45 percent DDGS or modified wet DDGS with solubles used in common progeny feedlot diet	Diets containing 100 or 125 percent of TDN requirements containing ground hay and DDGS or corn barn and ground corn stalks were fed to cows from 83 days prepartum until calving and fed a commong diet postpartum; progeny were fed a common diet containing 45 percent DDGS with solubles until slaughter	Cow BW, BCS, and calf birth weight were greater when fed the high energy diet, but no effects of diet on percentage of unassisted births, calving date, milk production, subsequent pregnancy rate among dietary treatments	No differences in calf weaning weight, initial and final feedlot BW, DMI, ADG, Gain:Feed, or morbidity among dam diet treatments	Wilson et al., 2016b
Cows in a fall-calving system, 632 kg; steers weaned at 186 days of age	Supplement contained 70 percent DDGS, 30 percent soybean hulls; Weaned steers fed 8.1 percent crude fat 25 to 45 percent modified wet DDGS	Grazing endophyte infected tall fescue/red clover pasture with no supplement or low (2.2 kg/cow/day) or high (8.6 kg/cow/day) supplement	Cows fed high amount of supplement had heavier BW pre-calving, post-calving, and post-breeding, but supplementation did not affect calf birth weight, mortality, or assistance with calving. Prepartum supplementation tended to improve AI conception but did not affect pregnancy rate. Early weaning and feeding supplements improved cow BW, BCS, and reproduction.	Weaned steers from cows fed the low supplement diet had greater BW at weaning compared with unsupplemented cows, but minimal performance differences on calf performance based on dam prepartum supplementation level.	Shoup et al., 2015
Spring-calving mature cows, 678 kg	DDGS crude fat content not reported	Limit-fed ground hay (12 kg/day) or a diet containing 60 percent ground corn stalks, 24 percent DDGS, 16 percent corn bran (10.4 kg/day) from 88 days prepartum to calving; postcalving diet contained 22 percent ground hay, 22 percent ground corn stalks, 33 percent DDGS, 24 percent corn bran; progeny fed a common feedlot diet containing wet corn gluten feed, high-moisture corn, corn husklage, and supplement	Cow BW and BCS, and calf birth weight were greater when fed the DDGS diet prepartum, and no difference in unassisted births, pregnancy rate, and milk production	No difference in progeny final BW, ADG, DMI, Gain:Feed, mortality, morbidity, HCW, LM area, backfat, marbling score, and YG during the feedlot feeding period	Wilson et al., 2015a

Table 9. Summary of 13 published studies evaluating beef cow reproductive performance and subsequent growth, carcass or reproductive responses[1] of progeny fed various types of DDGS diets since 2009

Reproductive phase	DDGS inclusion rate and crude fat content	Feeding conditions	Reproductive performance responses	Progeny growth, carcass, or reproductive responses	Reference
Fall-calving mature cows, 603 kg	0 or 2.1 kg DDGS/cow/day until calving; 43 percent DDGS during feedlot period; crude fat content was seven percent	Grazing tall fescue pasture with or without DDGS supplement for 69 days before calving, then moved to another pasture without supplementation; steer progeny fed a common feedlot diet containing 435 DDGS	Cows fed the DDGS supplement had greater BW and BCS, but there were no differences in calving date, milk production, AI conception, or pregnancy rate; no differences in calf birth or weaning weights, or preweaning ADG	No difference in initial and final BW, days on feed, ADG, DMI, Gain:Feed, morbidity, HCW, LM area, marbling score, or YG of progeny steers	Wilson et al., 2015b
Mature cows, 606 kg	4.1 kg/head/day; crude fat content not reported	Diets fed from 167 days of gestation until one week before calving included ad libitum access to grass hay with no supplement, or 5.3 kg/day of shelled corn or 4.1 kg/day of DDGS with 2.1 kg/day hay and 1 kg/day supplement	Cows fed DDGS gained more BW but BCS were not different compared with grass hay only or corn supplement; calf birth weight was increased by feeding DDGS but no effects on dystocia, conception rates, milk production, or milk composition	-	Radunz et al., 2010

Abbreviations used: ADG = average daily gain, AI = artificial insemination, BCS = body condition score, BW = body weight, DMI = dry matter intake, Gain:Feed = gain to feed ratio, HCW = hot carcass weight, LM = loin muscle, YG = yield grade

Table 10. Summary of four published studies evaluating beef heifer reproductive performance and subsequent growth, carcass, or reproductive responses of progeny fed various types of DDGS diets since 2009

Reproductive phase	DDGS inclusion rate and crude fat content	Feeding conditions	Reproductive performance responses	Progeny growth, carcass, or reproductive responses	Reference
Gestating heifers					
Yearling heifers		Dams fed diets fed from 192 days of gestation to 118 days postpartum consisted of corn silage TMR or corn residue with DDGS; heifer progeny provided ad libitum access to DDGS as creep feed until weaning and then fed corn silage, grass haylage, corn stover, soy hulls and soybean meal from weaning to AI	Progeny heifers from dams fed DDGS supplement had greater BW and frame score from weaning to breeding, but ovarian size, follicle count, and age at puberty were not affected by dam diet; BW at puberty and pregnancy rate from AI were greater when dams were supplemented with DDGS and did not affect dystocia rate	-	Gunn et al., 2015
Primiparous heifer, 450 kg	0.83 kg/day; crude fat content not reported	Three-year study during 142 days of gestation and fed grass hay with no supplement or isonitrogenous, isocaloric supplements containing DDGS or corn gluten	Unsupplemented heifers had less DMI and gain less BW. Supplements increased ADG but calf birth weight and subsequent pregnancy rates were similar.	Calf weaning and final BW was not affected by maternal diet and ADG and HCW was similar. Calves from cows fed low amount of supplement had the lowest carcass twelth rib fat and meat tenderness.	Summers et al., 2015a,b
Two-year old heifers, 199 kg	1.2 kg ground raw soybeans and 0.4 kg corn or 1.65 kg DDGS; 11.5 percent crude fat	Ad libitum access to late-harvested Sandhills meadow hay with raw soybean-corn or DDGS supplements from weaning to breeding	Feeding supplemental DDGS increased ADG in year 1 but was not different in year 2; no difference in follicle size, follicle hormones, or pregnancy rate between year 1 and 2; no difference between developmental diets on calf production	-	Martin et al., 2010
Late gestation heifers,	2.8 to 3.1 kg/head/day; 12 percent crude fat	Two-year study with 4 kg/head/day of grass hay with 2.8 to 3.1 kg/head/day of DDGS or 3.2 to 3.5 kg/head/day of soybean hulls for 190 days of gestation to calving	BW increased when feeding DDGS but no effect of supplement on BCS change, calving ease, calf vigor, calf birth weight, weaning weight, or ADG; cows fed DDGS had greater pregnancy rates but did not affect pregnancy distribution or estrus cycles	-	Engle et al., 2008

[1]Abbreviations used: ADG = average daily gain, AI = artificial insemination, BCS = body condition score, BW = body weight, DMI = dry matter intake, Gain:Feed = gain to feed ratio, HCW = hot carcass weight, LM = loin muscle, YG = yield grade

Replacement Heifers

Very little research has been conducted on feeding DDGS to replacement heifers. However, based upon numerous studies for finishing cattle, DDGS would be an excellent source of by-pass protein and energy for developing replacement heifers. In a study by MacDonald and Klopfenstein (2004), replacement heifers grazing brome grass were supplemented with 0, 0.45, 0.90, 1.36 or 1.81 kg of DDGS per day, and results showed that for each 0.45 kg of DDGS supplemented, forage consumption decreased by 0.78 kg per day and ADG increased by 27 g per day.

Loy et al. (2003) evaluated the value of supplementing DDGS daily or three times per week when feeding high-forage diets to growing crossbred heifers. Heifers were provided *ad libitum* access to grass hay (8.7 percent crude protein) and were supplemented with DDGS or dry-rolled corn. The supplements were fed at two feeding levels and offered either daily or three times per week in equal proportions. Heifers provided daily supplements ate more hay, had greater ADG, but had reduced feed conversion than heifers supplemented three times per week. However, providing low or and high supplementation levels of DDGS resulted in greater ADG and feed conversion than heifers fed the dry-rolled corn (**Table 11**). Based on these results, the calculated net energy value of DDGS was 27 percent greater than for corn grain.

In a subsequent study, Loy et al. (2004) fed cannulated heifers either no supplement, or DDGS supplemented daily or on alternating days, or dry-rolled corn supplemented daily or on alternating days. As expected, hay intake was greater for heifers that received no supplementation compared to those provided supplements, but there were no differences in feed intake between heifers supplemented with DDGS or corn, but heifers provided supplemental DDGS had higher rates of rumen fiber disappearance than heifers supplemented with corn.

Loy et al. (2008) determined the effect of supplement type, concentration and frequency of feeding on feed intake and growth performance to estimate the energy value of DDGS in a high-forage diet for growing heifers. Results of this study showed supplementing DDGS or dry-rolled corn three times weekly decreased forage intake and body weight gain compared with daily supplementation, but feeding DDGS improved body weight gain and gain:feed compared with feeding supplemental dry-rolled corn. They calculated the TDN of DDGS used in this study was estimated to be 118 to 130 percent the value of corn when fed as a supplement to a grass-hay diet for growing heifers.

Stalker et al. (2004) conducted two experiments to evaluate the effects of supplemental degradable protein requirements when DDGS was fed as an energy source in forage-based diets. Diets were formulated to be deficient (greater than 100 g/day) in degradable protein, but contained excess metabolizable protein. Results of this study showed that adding urea to meet the degradable protein intake requirement is not necessary when DDGS is used as an energy source in forage based diets.

Morris et al. (2005) showed that when individually fed heifers were provided high- or low-quality forage diets with supplementation of either 0, 0.68, 1.36, 2.04 or 2.72 kg DDGS per day, forage intake decreased and average daily gain increased. These results suggest DDGS can be an effective forage supplement to increase growth at times when availability of forage may be limited.

Islas and Soto-Navarro (2011) evaluated the effects of supplementation of DDGS on forage intake and digestion of beef heifers grazing small-grain pasture and showed that supplementation with DDGS up to 0.6 percent of body weight, increased lipid intake as well as lipid and NDF digestibility, with no adverse effects on intake, digestibility and characteristics of ruminal fermentation. Based on these results, DDGS can be successfully used as a supplement to increase lipid intake without negatively affecting forage intake or digestibility in cattle grazing small grains pasture.

Table 11. Growth performance of growing heifers fed native grass hay and supplemented with either corn or DDGS fed at low or high supplementation levels (adapted from Loy et al., 2003).

		Low (0.21 percent of body weight)	High (0.81 percent of body weight)
ADG, kg/d	**Corn**	0.37	0.71
	DDGS	0.45	0.86
dry matter Intake/ADG	**Corn**	15.9	9.8
	DDGS	12.8	8.0

Conclusions

Corn DDGS is an excellent energy and protein source for beef cattle in all phases of production. It can be effectively used as an energy source and be fed up to 40 percent of ration dry matter intake for finishing cattle with excellent growth performance and carcass and meat quality. However, at high dietary DDGS inclusion rates, excess protein and phosphorus will be consumed relative to requirements and result in increased excretion of nitrogen and phosphorus in manure. Sulfur content of DDGS should be monitored to adjust diet inclusion rates of DDGS if necessary, to avoid sulfur toxicity, especially when cattle are consuming forages and water with high-sulfur content. Feeding high-DDGS diets to finishing cattle has minimal effects on beef color, may improve sensory characteristics, but increase polyunsaturated fatty acid content which may reduce shelf-life of fresh beef over extended retail case storage periods.

There is no consistent effect of feeding DDGS on *E. coli* O157:H7 shedding in beef cattle. Dietary level of DDGS and type of corn processing (dry-rolled corn, high-moisture corn, steam-flaked corn) may affect the response to *E. coli* O157:H7 shedding. Currently, there is no scientific evidence suggesting the level of DDGS fed is a cause for *E. coli* O157:H7 contamination in ground beef.

Feeding supplemental DDGS to beef cows and heifers supports satisfactory reproductive and lactation performance with minimal effects on growth, carcass or reproductive performance of progeny. The best applications for using DDGS in beef cow diets are in situations where 1) supplemental protein is needed (especially when feeding low quality forages) to replace corn gluten feed or soybean meal, 2) a low-starch, high-fiber energy source is needed to replace corn gluten feed or soy hulls, and 3) when a source of supplemental fat is needed.

For growing heifers, adding urea to meet the degradable protein intake requirement is not necessary when DDGS is used as an energy source in forage based diets. DDGS can be an effective forage supplement to increase growth at times when availability of forage may be limited, and DDGS has 18 to 30 percent higher TDN value than dry-rolled corn for developing heifers.

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