CHAPTER 17

Reduced-Oil DDGS in Dairy Cattle Diets

Introduction

CORN DDGS IS AN EXCELLENT FEED INGREDIENT for use in lactating dairy cow rations, and about 30 percent of the 38 million metric tons of DDGS co-products produced in the U.S. are consumed by dairy cows. Distiller's grains are an excellent source of energy, readily fermentable fiber, protein and minerals for lactating dairy cows as well as dry cows and replacement heifers. Several excellent literature reviews have been published (Schingoethe et al., 2009; Kalscheur et al., 2012a,b; and Kalscheur, 2013) on the benefits, limitations and feeding applications corn DDGS to dairy cattle. Results from numerous studies have shown that including 20 percent DDGS in total mixed rations (TMR) is optimal for supporting maximum milk production and optimal milk composition (Schingoethe et al., 2009), while minimizing excess phosphorus excretion in manure (Schmit et al., 2009). The major concern with adding more than 20 percent DDGS to TMR is the possibility of causing milk fat depression because the lipid in DDGS is high in polyunsaturated fatty acids. The rumen unsaturated fatty acid load is often considered to be the most-likely risk factor for DDGS to cause milk fat depression, but it is not the only factor associated with milk fat depression (Kalscheur, 2013). Other risk factors that contribute to milk fat depression are variable nutrient composition, lack of adequate effective fiber from various ingredients and increased amounts of fermentable carbohydrates. In fact, Kalscheur (2005) showed feeding diets containing DDGS caused milk fat depression only when diets contained less than 50 percent forage or less than 22 percent NDF from forage. Therefore, when feeding high- (greater than 20 percent) DDGS diets, it is recommended at least 22 percent of total diet NDF be provided by forage. Furthermore, most of the DDGS produced today contains lower crude fat content (5 to 9 percent) compared to traditional high-oil DDGS (greater than 10 percent crude fat), which will result in less capacity for oil in DDGS to modify the rumen microbial environment and reduces the risk of milk fat depression. Therefore, if appropriate diet formulation approaches are used when feeding DDGS, milk fat depression is unlikely to occur.

Nutritional Composition of DDGS for Dairy Cattle

Nutritional advantages of DDGS for dairy cattle

There are several nutritional advantages of corn DDGS compared with other protein ingredients in dairy cow rations (Yildiz and Todorov, 2014).

1. Relatively high protein content (26 to 38 percent)
2. High-energy content (2.03 Mcal/kg NE_L)
3. High concentration of bypass protein (55 percent of crude protein)
4. Low-starch content reduces the potential of high-energy rations to cause rumen acidosis
5. Contains dried yeast cells that provide vitamins, improves palatability, increased fiber digestion and microbial protein synthesis
6. Highly digestible neutral detergent fiber (NDF) that increases energy content and stimulates rumen microorganisms
7. High methionine content provides the opportunity to blend feed ingredients with lower methionine content
8. Relatively high concentration (0.7 to 0.9 percent) of readily available and inexpensive source of phosphorus
9. Contains no anti-nutritional factors
10. Provides milk production performance comparable to feeding soybean meal and rapeseed meal despite its relatively low lysine content, which enables the lysine-to-methionine ratio to be closer to the recommended 3:1 without affecting milk protein content.

With all of these nutritional benefits from using corn DDGS as a feed ingredient in diets for lactating dairy cows, it is no wonder it is a very popular and widely used energy and protein supplement in the U.S. dairy industry.

Energy

Limited studies have been conducted to determine the energy content and nutrient digestibility of reduced-oil DDGS for ruminants. However, using available published information, Schingoethe et al. (2009) summarized published energy values for corn DDGS and reported the average to be 2.25 Mcal NE_L/kg dry matter, which is about 10 percent greater than corn, and greater than 1.97 Mcal NE_L/kg dry matter reported by NRC (2001). This is due to the relatively high (5 to 12 percent) crude fat content and high proportion of readily digestible fiber (38 percent NDF) in corn DDGS. Fiber in DDGS contains low-lignin content which facilitates high digestibility (62 to 71 percent; Birkelo et al., 2004; vander Pol et al., 2009).

Nuez-Ortín and Yu (2011) used the NRC chemical summary and biological approaches to predict energy values of new co-products from bioethanol production for dairy cows, and estimates are shown in **Table 1**. Using this approach, true digestible protein and non-fiber carbohydrate is less in corn DDGS than wheat DDGS, but corn DDGS has much greater digestible fatty acids and NDF than wheat DDGS. As a result, the NE_L at 3× maintenance was comparable (2.3 Mcal/kg dry matter) reported by Schingoethe et al. (2009).

Recently, Foth et al. (2015) determined the energy value of reduced-oil DDGS (6.2 percent crude fat) in lactating dairy cows to be 3.82 Mcal DE/kg dry matter at 1× maintenance, 3.41 Mcal ME/kg dry matter at 1× maintenance, and 2.03 Mcal NE_L/kg dry matter at 3×maintenance. These estimates are lower than those reported by Schingoethe et al. (2009) for high-oil (less than 10 percent crude fat) DDGS sources, but similar to the NE_L value reported by NRC (2001). In summary, results from these limited studies suggest the NE_L content at 3× maintenance for high-oil DDGS is 2.25 to 2.30 Mcal/kg dry matter, and about 2.0 Mcal/kg dry matter for reduced-oil DDGS.

Oil content and fatty acid composition of DDGS

One of the primary concerns about using corn DDGS in lactating dairy cow diets is the relatively high crude fat content and concentrations of unsaturated fatty acids which may result in reduced milk fat content. Several surveys of dairy nutritionists (Owens, 2009a) and dairy producers (NASS, 2007) indicated the high crude fat content of DDGS was of moderate to high concern and a primary reason why they did not use DDGS in lactating dairy cow rations.

However, in a meta-analysis of 24 experiments, Kalscheur (2005) showed feeding diets containing DDGS caused milk fat depression only when diets contained less than 50 percent forage or less than 22 percent NDF from forage. Furthermore, most of the DDGS produced today contains lower crude fat content (5 to 9 percent) compared to traditional high-oil DDGS (greater than 10 percent crude fat), which will result in less capacity for oil in DDGS to modify the rumen microbial environment and reduces the risk of milk fat depression. Diaz-Royón et al. (2012) summarized the fatty acid composition of corn DDGS sources from several studies and results are shown in **Table 2**. The most abundant fatty acids in corn oil extracted from DDGS are linoleic (C18:2) and oleic (C18:1), which represent about 74 percent of the total fatty acids in DDGS. However, from this summary, the fatty acid composition can be quite variable among DDGS sources, labs and analytical procedures.

Rumen degradable and digestible undegraded protein of DDGS

Yildiz and Todorov (2014) summarized published studies that determined rumen degradable protein (RDP) and digestibility of undegraded protein in the small intestine (dRUP) of corn DDGS (**Table 3**). The large variation in rumen degradability and small intestine digestibility of protein in corn DDGS is likely due to differences in drying temperatures used by ethanol plants when producing DDGS. Similar variation has also been shown for amino acid digestibility, especially lysine, of DDGS among sources for swine and poultry. However in general, the rumen degradability of corn DDGS is relatively low, which is an advantage in ruminant diets. Corn DDGS is a good source of dRUP that ranges between 47 to 64 percent of crude protein. Furthermore, intestinal digestibility of most amino acids exceeds 93 percent, which is slightly less than for soybean meal, except for lysine which is about 8 percent digestible in DDGS compared with 97 percent digestibility in soybean meal. However, data provided by

Table 1. Comparison of true digestible nutrient content and energy value of wheat and corn DDGS using an in situ assay (dry matter basis; adapted from Nuez-Ortín and Yu, 2011)

Measurement	Wheat DDGS	Corn DDGS
True digestible crude protein %	33.5	22.7
True digestible non-fiber carbohydrate %	23.6	6.4
True digestible fatty acids %	3.7	15.1
True digestible NDF %	17.3	33.9
Predicted energy content		
$DE_{3\times}$, kcal/kg dry matter (dairy)	3,470	3,791
$ME_{3\times}$, kcal/kg dry matter (dairy)	3,069	3,439
$NE_{L3\times}$, kcal/kg dry matter (dairy)	1,979	2,299
NE_m, kcal/kg dry matter (beef)	2,110	2,340
NE_g, kcal/kg dry matter (beef)	1,439	1,630

Table 2. Summary of studies reporting the fatty acid composition (percent of total fatty acids) in corn DDGS (adapted from Diaz-Royón et al., 2012)

Fatty acid	Tang et al. (2011)	Ranathunga et al. (2010)	Nyoka (2010)	Owens (2009b)	Martinez-Amezcua et al. (2004)	Anderson et al. (2006)	Average
C12:0	0.02	ND	ND	0.01	0.04	0.78	0.21
C14:0	0.07	0.42	3.95	0.38	0.09	2.45	1.23
C16:0	16.7	14.7	16.9	12.5	12.8	15.5	14.9
C16:1	0.16	0.13	2.46	0.11	0.18	ND	0.61
C18:0	2.62	1.99	2.82	1.68	2.03	2.38	2.25
C18:1	23.1	26.9	21.4	38.2	23.2	17.0	25.0
C18:2	53.7	50.7	40.2	40.3	56.3	52.5	49.0
C18:3	0.45	1.60	1.44	1.05	1.48	4.79	1.80
C20:0	1.99	0.39	0.55	0.26	0.39	1.45	0.84
C20:1	0.29	0.22	3.46	0.14	0.27	ND	0.88
C20:2	ND	0.03	0.13	0.03	0.05	ND	0.06

Table 3. Rumen degradable protein and digestibility of rumen undegraded protein in the small intestine of DDGS for dairy cows (adapted from Yildiz and Todorov, 2014)

Rumen degradable protein (RDP) %	Digestible rumen undegradable protein (dRUP) %	Reference
46.0	-	Firkins et al., 1984
63.3	50.5	Carvalho et al., 2005
48.7	88.8	MacDonald et al., 2007
57.0	86.2	Kononoff et al., 2007
22.0 – 36.5	-	Kleinschmit et al., 2007a
47.0 – 64.0	-	Schingoethe et al., 2009
38.0	64.0	Cao et al., 2009
-	92.4	Mjoun et al., 2010c
43.7 – 66.9	91.9 – 92.1	Kelzer et al., 2010
45.0	-	Schingoethe et al., 2009
69.3	-	Oba et al., 2010

Schingoethe et al. (2009) and Mjoun et al., 2010c showed the concentrations of amino acids, especially lysine (3.15 percent of crude protein) and their intestinal digestibility in corn DDGS are greater than those reported in NRC (2001).

Amino acid digestibility

High-producing lactating dairy cows require high daily intake of crude protein and improved supply and balance of amino acids entering the duodenum to meet the high requirements for milk production and milk protein synthesis. It is generally accepted that the concentration of milk protein slightly increases when feeding increased dietary protein levels to lactating dairy cows. No single feed ingredient contains an adequate amount of rumen undegradable protein with an ideal balance of essential amino acids that matches the amino acid profile of milk and the requirements for optimal milk production. As a result, it is difficult to formulate lactating dairy cow rations that meet the daily requirements all of essential amino acids for milk production using commonly available feed ingredients.

Interest in supplementing rumen-protected lysine in lactating dairy cow diets containing DDGS has been significant in recent years because corn protein sources, such as DDGS, have amino acid profiles that do not match the amino acid profile of milk, and are especially low in lysine content. Balancing diets for metabolizable protein is difficult when using current metabolic models because of variability in feed ingredients, genetic differences in milk yield among cows, environment conditions and their interactions, which leads to inaccurate prediction of intestinally absorbed amino acids. However, several studies have been conducted to evaluate the effectiveness of supplementing dairy cow diets containing DDGS with ruminally protected lysine to determine the potential benefits in milk yield and composition.

Boucher et al. (2009) measured intestinal amino acid digestibility of the rumen-undegraded protein fraction of five sources of DDGS to determine if it contains a constant protein fraction undegradable in the rumen and indigestible in the small intestine. Results from this study showed DDGS does not contain a constant protein fraction both undegradable in the rumen and indigestible in the small intestine. Therefore, based on indigestibility values obtained in this experiment, it appears DDGS contains a protein fraction indigestible in the intestine but partially degradable in the rumen, digestible in the intestine after rumen incubation or both.

Swanepoel et al. (2010a) estimated the rumen escape potential of a ruminally protected lysine product and determined its effects on feed intake, digestibility, milk production and milk composition of high producing dairy cows. Feeding diets supplemented with rumen-protected lysine had no effect on dry matter intake, milk yield or milk true protein and lactose yields, but milk fat concentration and yield decreased. Plasma concentrations of most amino acids, except lysine, decreased when rumen-protected lysine was fed. This suggests lysine was the first limiting amino acid in these diets, and supplementing diets with rumen-protected lysine improved absorption and utilization of other amino acids. However, rumen-protected lysine supplementation had no effect on milk protein synthesis and decreased plasma 3-methylhistidine concentrations, which suggests muscle protein synthesis may have been increased or degradation was reduced. Although lysine may have affected muscle protein turnover and energy metabolism resulting in difference in intake, metabolism and absorption of amino acids, as well as milk production, these researchers recommended not supplementing diets with rumen-protected lysine due to potential negative outcomes resulting in poor predictability of estimating intestinally absorbed lysine requirements.

In a subsequent study, Swanepoel et al. (2010b) compared the use of three metabolic prediction models to estimate the amino acid profiles of intestinally delivered protein in dairy rations and determine if there was enough consistency in nutrient profiles to develop and supplement a common ruminally-protected amino acid premix. Although these researchers reported there appears to be enough consistency in nutrient profiles among commonly used rations to support the use of a ruminally-protected amino acid complex to balance dairy rations, they indicated it was impossible to determine which model predictions were correct.

Robinson et al. (2011) also estimated the rumen escape of ruminally protected lysine in lysine-deficient diets, and its effects on dry matter intake, milk production and plasma amino acid profiles of high producing dairy cows. Feeding rumen-protected lysine increased plasma lysine concentrations in mid-lactation cows, which suggested lysine requirements were exceeded, and supplemental rumen-protected lysine was not needed. Based on previous research from this group, they suggested that body protein turnover is the first priority for amino acid utilization followed by milk component systhesis.

Li et al. (2012) conducted a study to determine in situ ruminal degradability of crude protein, amino acid profiles of ruminal undegradable protein (RUP) and in vitro intestinal digestibility of amino acids for wheat and corn grain and wheat and corn DDGS sources. Ruminal degradation of crude protein was less in DDGS than in corresponding grains, but there was no difference between wheat and corn DDGS. Ruminal degradation of essential amino acids was greater for wheat DDGS compared with corn DDGS, and amino acid profiles of RUP were different among grain types and DDGS sources. Total and essential amino acid intestinal digestibility was highly variable among individual amino acids and feed ingredients, but were not different between wheat and corn DDGS. These results suggest that amino acid availability varies substantially among grain and DDGS sources.

Paz et al. (2013) fed 0, 10 or 20 percent DDGS diets with or without rumen protected lysine (60g/day) to determine effects on milk yield, milk composition and plasma concentrations of amino acids. Cows fed 10 or 20 percent DDGS diets had similar dry matter intake and milk yield compared with cows fed the control diet. Cows fed the 20 percent DDGS diets had greater milk protein concentration and yield, but other milk components were similar, compared with those fed the 0 and 10 percent DDGS diets. Supplementation of rumen-protected lysine in DDGS diets had no effect on milk production or composition. Plasma concentrations of arginine, histidine and valine were lower, and concentrations of leucine and methionine were greater in cows fed the DDGS diets compared with those fed the 0 percent DDGS diet. Although the plasma concentration of lysine decreased as dietary inclusion rate of DDGS increased, supplementation of diets with rumen-protected lysine did not decrease plasma concentrations of other essential amino acids, indicating lysine was not limiting in these diets.

In a subsequent study, Paz and Kononoff (2014) evaluated the effects of feeding isonitrogenous and isocaloric diets containing 15 or 30 percent reduced-oil DDGS with or without rumen-protected lysine supplementation on lactation responses and amino acid utilization. Diet inclusion rate of reduced-oil DDGS had no effect on dry matter intake, milk yield or milk fat and lactose concentrations, but milk protein content decreased when cows were fed diets containing 30 percent reduced-oil DDGS. However, cows fed the 305 reduced-oil DDGS diets had greater amino acid extraction efficiency, and tended to have greater milk protein concentration when the diet was supplemented with rumen-protected lysine, than cows fed the 15 percent DDGS diets. This observation suggests lysine was inadequate in the 30 percent DDGS diets, but there was no difference in milk protein yield among dietary treatments. These researchers speculated the rumen-protected lysine product used, provided less metabolizable lysine than expected, and indicated that lysine, arginine and phenylalanine were the three most limiting amino acids in these diets. These results suggest supplementing lactating dairy cow diets with rumen-protected amino acid may be useful in supplying deficient amino acids, but accurate information about the bioavailability of these amino acids is needed.

Mjoun et al. (2010a) determined the ruminal degradability and intestinal digestibility of protein and amino acids in solvent-extracted soybean meal, expeller soybean meal, extruded soybeans, high-oil DDGS, reduced-oil DDGS, high-protein distillers dried grains and modified wet DDGS with solubles using in situ and in vitro procedures. Intestinal digestibility of most amino acids in the corn DDGS co-products exceeded 92 percent and was slightly less than for the soybean products, except for lysine, which averaged 84.6 percent in distillers co-products compared with 97.3 percent in the soybean products. Results from this study suggest that amino acid availability is comparable between corn DDGS co-products and soybean products for lactating dairy cows.

Mjoun et al. (2010b) evaluated milk production responses and amino acid utilization when feeding diets containing 0 percent DDGS, 22 percent high-oil (percent crude fat), or 20 percent reduced-oil DDGS to dairy cows in early lactation. Diets were formulated to contain similar crude protein, lipid, NDF and NE content. Body weight, body weight change and body condition scores were similar among dietary treatments, but cows fed the control diet tended to increase body condition compared to those fed the DDGS diets (**Table 4**). There were no differences in dry matter intake, protein intake and net energy. All cows had a positive energy balance from 35 to 120 days in lactation, but cows fed the control diet had greater energy balance, tended to have greater total body energy reserves and less energy efficiency than cows fed the DDGS diets. These results suggest that cows fed the control diet may have preferentially partitioned metabolizable energy toward body energy reserves rather than using this energy for milk production and milk component synthesis. There were no differences in milk yield, or milk fat and lactose content among dietary treatments, but cows fed the DDGS diets had greater milk protein content and yield. Furthermore, feed efficiency tended to be greater and nitrogen efficiency was greater for cows fed the DDGS diets. Amino acid utilization was determined at the peak of milk production (nine weeks of lactation), and showed the extraction efficiency of lysine by the mammary gland was greater when cows were fed the DDGS diets (76 percent) compared to those fed the control diet (65 percent), but mammary uptake of lysine was similar (2.56 g/kg milk) among dietary treatments. Furthermore, mammary uptake of methionine tended to increase in cows fed the DDGS diets. Despite the apparent lysine deficiency, milk protein concentration was increased in cows fed the DDGS diets. These results strongly indicate high-oil and reduced-oil DDGS are good sources of energy and metabolizable amino acids when added at 20 percent of the diet, and lysine content and availability does not limit milk production or milk protein synthesis in lactating dairy cows producing 40 kg of milk per day.

Mjoun et al. (2010c) also evaluated the effects of feeding diets containing 0, 10, 20 or 30 percent low-oil (3.5 percent crude fat) DDGS (to replace soybean meal) to dairy cows in mid-lactation on milk production and composition, as well as amino acid utilization. Increasing dietary DDGS content had no effect on dry matter intake and milk yield, and linearly increased milk fat content while tending to increased milk fat yield. Milk protein yield was not affected by increasing dietary DDGS inclusion level, but milk protein concentration increased quadratically. The efficiency of milk production increased but nitrogen utilization efficiency was not affected by increasing dietary DDGS content. The extraction of lysine from the mammary gland increased linearly, and extraction of methionine decreased linearly. Results from this study showed feeding diets containing up to 30 percent low-oil DDGS provide similar lactation performance and nutritional efficiency compared to cows fed the control soybean protein-based diet.

Pereira et al. (2015) determined the effects of feeding DDGS diets supplemented with rumen-protected lysine and methionine to replace soybean meal on lactation performance of late-lactation cows. Results showed supplementing DDGS diets with rumen-protected lysine and methionine was effective in maintaining milk yield and milk composition when replacing soybean meal in low protein corn silage and rye grass silage diets for late lactation dairy cows producing 21 to 27 kg milk/day.

Table 4. Lactation performance, energy and amino acid utilization and milk composition of feeding high-oil or reduced-oil DDGS to early lactation dairy cows (adapted from Mjoun et al., 2010a)

Measure	Control	22% High-oil DDGS	20% Reduced-oil DDGS
Cow body weight and condition			
Initial body weight, kg	693	682	660
Final body weight, kg	734	722	704
Body weight change, kg/day	0.47	0.47	0.53
Body condition score[1]	3.43	3.32	3.34
Body condition score change/day	0.14	0.02	0.00
dry matter, protein, and energy intake			
Dry matter intake, kg/day	24.8	24.7	24.6
Protein intake, kg/day	4.3	4.3	4.3
NE_I, Mcal/day[2]	41.3	40.1	40.3
NE_M, Mcal/day[3]	11.0	11.0	11.0
NE_L, Mcal/day[4]	26.4	26.5	27.4
Energy balance, Mcal/day[5]	4.39	1.98	1.98
Total energy reserves[6]	20.7	20.0	20.1
Energy efficiency[7]	63.1	66.9	68.1
Milk production and efficiency			
Milk yield, kg/day	39.2	38.9	39.8
Energy-corrected milk yield[8]	38.0	37.8	39.5
Fat-corrected milk yield[9]	35.7	35.3	37.1
Feed efficiency[10]	1.50	1.57	1.61
Nitrogen efficiency[11]	24.5	26.9	26.5
Mammary uptake of essential amino acids, g/kg milk[12]			
Histidine	0.80	0.91	0.98
Isoleucine	2.07	2.40	2.45
Leucine	3.09	4.03	4.38
Lysine	2.52	2.49	2.68
Methionine	0.58	0.83	0.81
Phenylalanine	1.14	1.39	1.58
Threonine	1.18	1.19	1.30
Tryptophan	0.14	0.64	0.50
Valine	2.35	2.87	2.87

Table 4. Lactation performance, energy and amino acid utilization and milk composition of feeding high-oil or reduced-oil DDGS to early lactation dairy cows (adapted from Mjoun et al., 2010a)

Measure	Control	22% High-oil DDGS	20% Reduced-oil DDGS
Milk composition			
Fat %	3.63	3.24	3.57
Fat, kg/day	1.33	1.34	1.40
Protein %	2.82	2.88	2.89
Protein, kg/day	1.07	1.15	1.14
Lactose %	4.90	4.99	4.96
Lactose, kg/day	1.94	1.94	1.96
Total solids %	12.3	12.0	12.4
Total solids, kg/day	4.73	4.70	4.90
Milk urea nitrogen, mg/dL	11.8	10.9	10.1
Somatic cell score[13]	3.38	3.91	3.83

[1]Body condition score: 1 = emaciated to 5 = obese

[2]NE_I = Net energy intake (NE_L, Mcal/kg × dry matter intake, kg/day)

[3]NE_M = net energy for maintenance = Body weight$^{0.75}$ × 0.08; NRC (2001)

[4]NE_L – net energy required for lactation = [milk yield, kg × (0.029 x milk fat %) + (0.0563 × milk protein %) + (0.0395 × lactose %); NRC (2001)

[5]Energy balance = NE_I – (NE_M + NE_L)

[6]Total energy reserves = (proportion empty body fat × 9.4) + (proportion empty body protein × 5.55); NRC (2001)

[7]Energy efficiency = NE_L/NE_I × 100

[8]Energy-corrected milk = [0.327 × milk yield, kg] + [12.95 × fat yield, kg] + [7.2 × protein yield, kg]

[9]Fat-correct milk = [0.4 × milk yield, kg] + [15 × fat yield, kg]

[10]Feed efficiency = (energy-corrected milk/dry matter intake) × 100

[11]Nitrogen efficiency = (milk nitrogen, kg/day)/(nitrogen intake, kg/day) × 100

[12]Mamary uptake = arterio-venous difference × mammary plasma flow

[13]Somatic cell score = log somatic cell count

Phosphorus

Phosphorus is one of the most important and costly minerals in animal nutrition, but it is also considered one of the primary contributors to pollution in intensive animal production systems because when it is fed in excess, high concentrations of phosphorus are excreted in manure (Humer and Zebeli, 2015). Schmit et al. (2009) showed including moderate levels (10 percent) in lactating dairy cow rations did not significantly increase phosphorus excretion, but when DDGS is added to dry cow and heifer rations, the amount of plant-available phosphorus increased and exceeded crop nutrient requirements for phosphorus when manure from these cattle was applied.

Phosphorus content in DDGS is high (0.65 to 0.95 percent), and has been shown to be highly available in ruminant diets (Mjoun et al., 2008), and because high-producing dairy cows need supplemental phosphorus in their rations, the addition of DDGS can be used to partially replace expensive inorganic phosphorus supplements. Therefore, to minimize excess phosphorus excretion in manure, dairy cow rations should be formulated to be close to the cow's daily phosphorus requirement (NRC, 2001).

Summary of Initial Studies on Feeding High-Oil DDGS on Lactation Performance and Milk Composition

Schingoethe et al. (2009) summarized numerous studies involving the feeding value of high-oil DDGS for dairy cattle. Corn DDGS is a good source of crude protein (greater than 30 percent CP on a dry matter basis) which is high in ruminally undegradable protein (about 55 percent of crude protein). Corn DDGS is also an excellent source of energy (net energy for lactation is approximately 2.25 Mcal/kg of dry matter), which is derived from the intermediate oil concentration (5 to 12 percent on a dry matter basis) and readily digestible fiber (about 39 percent neutral detergent fiber). Lactation performance is usually similar when cows are fed wet or DDGS, but some research results show a slight advantage for feeding wet DDGS with solubles. Corn DDGS can be used as a partial replacement for both concentrates and forages, but it generally used as a concentrate replacement. This is because adequate effective fiber is needed to avoid milk fat depression when DDGS is used to replace forages in lactating cow diets. Lactating dairy cow diets can contain 20 to 30 percent DDGS on a dry matter basis provided that diets are nutritionally balanced. In fact, several studies have shown feeding DDGS diets containing up to 30 percent DDGS provide similar or increased milk production compared with when cows are fed diets containing common feed ingredients. Although DDGS can be added to lactating dairy cow diets at levels greater than 30 percent (dry matter basis), gut fill may limit dry matter intake and milk production. The fiber in DDGS, is usually considered a replacement for high-starch feed ingredients such as corn, and as a result, minimizes the risk of acidosis but does not necessarily eliminate it.

Kalscheur (2005) conducted a meta-analysis of data from 23 previous experiments and 96 treatment comparisons involving feeding wet (WDG) or dried corn distiller's grains with solubles (DDGS) to lactating dairy cows. These studies were published between 1982 and 2005 and evaluated feeding high-oil DDGS. A summary of several recent studies involving feeding reduced-oil DDGS will be discussed later in this chapter. To evaluate the effects of dietary inclusion rate of wet and dried corn distiller's grains on lactation performance, treatments were divided into five categories of feeding levels: 0 percent, 4 to 10 percent, 10 to 20 percent, 20 to 30 percent and greater than 30 percent on a dry matter basis. The form of the distiller's grains (wet or dried) was also used to separate responses in the analysis.

Dry matter intake (DMI) was affected by both dietary inclusion level and form of the distiller's grains fed (**Table 5**). For lactating cows fed DDGS, dry matter intake increased as the dietary DDGS inclusion level increased, and was greatest for cows fed diets containing between 20 and 30 percent DDGS. In fact, these cows consumed 0.7 kg more feed per day (dry matter basis) than cows fed the control diets containing no DDGS. Cows fed greater than 30 percent DDGS consumed about the same amount of feed as cows fed control diets. While DMI was increased for cows fed diets containing up to the 20 to 30 percent DDGS, DMI of cows fed WDG diets was greatest at lower inclusion levels (4 to 10 percent and the 10 to 20 percent levels). When WDG was included at concentrations greater than 20 percent, DMI decreased, and cows fed greater than 30 percent WDG had 2.3 kg/day less DMI than the control group, and 5.1 kg/d less than those fed the 4 to 10 percent dietary WDG levels. These results show corn DDGS is highly palatable because DMI is stimulated when DDGS is included up to 20 percent of the dry matter in dairy cow diets. Decreases in feed intake at higher inclusion levels may be caused by high dietary fat concentrations, or in the case of WDGS, high dietary moisture content.

Milk production was not affected by wet or dry form of distiller's grains fed, but there was a curvilinear response to increasing distiller's grains in dairy cow diets (**Table 5**). Cows fed diets containing 4 to 30 percent distiller's grains produced the same amount of milk (about 0.4 kg/d more milk), than cows fed diets containing no distiller's grains. When cows were fed the highest dietary inclusion rate (greater than 30 percent) of distiller's grains, milk yield tended to decrease, and produced about 0.8 kg/day less milk than cows fed diets containing no distiller's grains. However, cows fed more than 20 percent WDG had decreased milk production, which was most likely related to reduced DMI.

Milk fat percentage varied when feeding wet or dried distiller's grains, but was not affected by dietary level or moisture content (**Table 6**). Milk fat composition responses observed in this extensive data summary do not support the

Table 5. dry matter intake and milk yield of dairy cows fed increasing dietary levels of wet or dried corn distiller's grains (Kalscheur, 2005)

Diet inclusion level	Dry matter intake, kg/d			Milk yield, kg/d		
(Dry matter basis)	Dried	Wet	All	Dried	Wet	All
0%	23.5^{c}	20.9^{b}	22.2^{b}	33.2	31.4	33.0
4 – 10%	23.6^{bc}	23.7^{a}	23.7^{a}	33.5	34.0	33.4
10 – 20%	23.9^{ab}	22.9^{ab}	23.4^{ab}	33.3	34.1	33.2
20 – 30%	24.2^{a}	21.3^{ab}	22.8^{ab}	33.6	31.6	33.5
> 30%	23.3^{bc}	18.6^{c}	20.9^{c}	32.2	31.6	32.2
SEM	0.8	1.3	0.8	1.5	2.6	1.4

[a,b,c] Values within a column followed by a different superscript letter differ (P less than 0.05).
No superscript within a column indicates that there was no significant difference between distiller's grains dietary inclusion level.

concerns that feeding high dietary inclusion rates of distiller's grains results in milk fat depression. Many factors can affect milk fat depression, and can be avoided by providing sufficient fiber from forages to maintain adequate rumen function. Distiller's grains are comprised of 28 to 44 percent neutral detergent fiber, but this fiber is finely processed and rapidly digested in the rumen. As a result, fiber from distiller's grains is not considered ruminally effective fiber and should not be considered equal to forage fiber. In addition, high levels of dietary lipid provided from distiller's grain may affect rumen function leading to milk fat depression, but in genral, it is a combination of several dietary factors that can lead to significant reduction in milk fat percentage.

Milk protein percentage was not different among cows fed diets containing 0 to 30 percent distiller's grains, and the form of the distiller's grains did not alter milk protein composition (**Table 6**). However, milk protein percentage decreased 0.13 percentage units when distiller's grains was included at concentrations greater than 30 percent of the diet compared to cows fed control diets. At the higher dietary inclusion levels, distiller's grains most likely replaced all other sources of protein in the diet. At these high levels of dietary inclusion, lower intestinal protein digestibility, lower lysine concentrations and an unbalanced amino acid profile may have contributed to a reduced milk protein concentration. However, it should be noted the lower milk protein concentrations were more commonly reported in studies conducted in the 1980s and 1990s when the nutrient composition and digestibility of DDGS was different than that produced currently. Results for recent studies have not shown this effect. Lysine is very heat sensitive, and can be negatively affected in DDGS by high temperatures used during the production and drying in some ethanol plants. However, production and drying technology has improved dramatically in ethanol plants since the time these studies were conducted, resulting in improved lysine and amino acid digestibility of DDGS.

Recent Studies Evaluating the Effects of Feeding High-Oil and Reduced-Oil DDGS on Lactation Performance, Milk Composition, Rumen Fermentation and Nutrient Digestibility

Several recent studies have shown numerous benefits of feeding diets containing up to 30 percent high-oil and reduced-oil DDGS diets to lactating dairy cows on milk yield and composition, as well as reductions in methane emissions and the underlying rumen fermentation and nutrient digestibility responses that support these responses. Understanding the effects of feeding corn DDGS to lactating dairy cows on rumen fermentation and nutrient digestibility is important for several reasons including impacts on methane emissions, manure composition and nutrient excretion, as well as potential risk of depressing milk fat content.

Benchaar et al. (2013) evaluated the effects of replacing corn and soybean meal with 0, 10, 20 or 30 percent high-oil DDGS in lactating dairy cow diets on enteric methane emissions, ruminal fermentation characteristics, apparent total tract digestibility, nitrogen balance and milk production of dairy cows. Increasing dietary DDGS levels increased dry matter intake and milk yield, but decreased apparent-total tract digestibility of dry matter and gross energy (**Table 7**). The acetate to propionate ratio in the rumen decreased linearly as a result of decreased acetate concentration, and methane production decreased linearly with increasing dietary DDGS levels. The reduction in methane production was attributed to increased amounts of lipid provided by DDGS and its effects on rumen fiber degradation, acetate:propionate and protozoa numbers. Nitrogen utilization efficiency was also improved by feeding increasing levels of DDGS, but nitrogen excretion in manure also increased. Results from this study indicate that feeding DDGS to lactating dairy cows is effective in reducing methane emissions while also improving dry matter intake and milk yield.

Table 6. Milk fat and protein concentrations from dairy cows fed increasing levels of wet or dried corn DDGS (Kalscheur, 2005)

Distillers grains inclusion level (dry matter basis)	Milk fat %	Milk protein %
0%	3.39	2.95[a]
4 – 10%	3.43	2.96[a]
10.1 – 2%	3.41	2.94[a]
20.1 – 30%	3.33	2.97[a]
> 30%	3.47	2.82[b]
SEM	0.08	0.07

a,b Values within a column followed by a different superscript letter differ (P less than 0.05).

No superscript within a column indicates that there was no significant difference between distiller's grains dietary inclusion level.

Table 7. Effects of feeding increasing levels of reduced-oil DDGS to lactating dairy cows on lactation performance, rumen pH, rumen volatile fatty acid and ammonia production, apparent total tract digestibility of nutrients and fecal output (adapted from Benchaar et al., 2013)

Measure	0% DDGS	10% DDGS	20% DDGS	30% DDGS
Initial body weight, kg	700	701	697	698
Final body weight, kg	710	714	724	730
Weight gain, kg/day	0.29	0.35	0.76	0.95
Dry matter intake, kg/day	24.2	24.6	24.4	25.3
Milk yield, efficiency, and composition				
Milk yield, kg/day	32.6	35.1	35.8	36.6
Energy-corrected milk yield, kg/day[1]	35.3	37.8	37.3	37.1
4% fat-corrected milk, kg/day[2]	32.1	34.5	34.1	33.7
Milk/dry matter intake	1.40	1.44	1.44	1.45
Energy-corrected milk/dry matter intake	1.51	1.55	1.50	1.46
Fat-corrected milk/dry matter intake	1.37	1.42	1.37	1.33
Milk fat %	3.93	3.91	3.69	3.47
Milk fat yield, kg/day	1.27	1.36	1.32	1.27
Milk protein %	3.49	3.41	3.31	3.31
Milk protein yield, kg/day	1.13	1.19	1.18	1.20
Milk lactose %	4.60	4.63	4.59	4.58
Milk lactose yield, kg/day	1.50	1.62	1.65	1.68
Milk urea nitrogen, mg/dL	11.1	10.0	9.9	10.6
Somatic cell count ($\times 10^3$/mL)	75	82	133	89
Rumen pH				
Minimum	5.92	5.92	5.98	5.97
Maximum	6.56	6.59	6.64	6.55
Average	6.21	6.21	6.27	6.22
Protozoa ($\times 10^5$/mL)	5.12	5.28	5.42	4.48
Volatile fatty acids				
Total, m*M*	99.3	96.1	93.6	91.1
Acetate, mol/100 mol	63.4	62.7	61.8	60.1
Propionate, mol/100 mol	21.8	22.1	22.3	23.1
Isobutyrate, mol/100 mol	0.8	0.8	0.7	0.7
Butyrate, mol/100 mol	11.5	12.0	12.8	13.7
Isovalerate, mol/100 mol	1.4	1.2	1.2	1.1
Valerate, mol/100 mol	1.2	1.2	1.2	1.3
Acetate:Propionate	63.4	62.7	61.8	60.1
Ammonia, mg/dL	8.4	7.5	6.7	6.1

Table 7. Effects of feeding increasing levels of reduced-oil DDGS to lactating dairy cows on lactation performance, rumen pH, rumen volatile fatty acid and ammonia production, apparent total tract digestibility of nutrients and fecal output (adapted from Benchaar et al., 2013)

	0% DDGS	10% DDGS	20% DDGS	30% DDGS
Methane production				
g/day	495	490	477	475
g/kg dry matter intake	0.6	20.1	19.7	18.9
% of gross energy intake	6.09	5.80	5.61	5.23
% of digestible energy intake	8.75	8.39	8.17	7.74
g/kg milk	15.6	14.2	13.6	13.2
g/kg fat-corrected milk	15.7	14.3	14.3	14.4
g/kg energy-corrected milk	14.3	13.1	13.0	13.0
g/kg milk fat	396	363	372	390
g/kg milk protein	446	415	411	400
Nutrient intake. apparent total tract digestibility of nutrients, and nitrogen balance				
Dry matter intake, kg/day	23.4	24.4	24.8	25.2
Dry matter digestibility %	70.7	70.2	69.6	68.1
Organic matter intake, kg/day	21.7	22.7	22.9	23.3
Organic matter digestibility %	72.5	71.9	71.1	69.8
Gross energy intake, Mcal/day	104	111	115	119
Gross energy digestibility %	69.6	69.2	68.7	67.6
Neutral detergent fiber intake, kg/day	7.5	8.2	9.0	9.5
Neutral detergent fiber digestibility %	56.0	56.9	57.4	54.8
Acid detergent fiber intake, kg/day	5.1	5.3	5.7	5.9
Acid detergent fiber digestibility %	60.6	60.4	60.3	60.6
Crude protein intake, kg/day	3.8	4.0	4.1	4.3
Crude protein digestibility %	67.3	68.3	68.4	69.2
Starch intake, kg/day	4.3	3.9	3.4	2.8
Starch digestibility %	94.7	95.4	96.2	98.8
Ether extract intake, kg/day	0.9	1.2	1.5	1.8
Ether extract digestibility %	53.0	53.8	57.4	59.4
Nitrogen intake, g/day	606	642	655	682
Fecal nitrogen excreted, g/day	198	204	207	211
Fecal nitrogen excreted as percent of N intake	32.7	31.7	31.6	30.8
Urinary nitrogen excreted, g/day	204	209	213	223
Urinary nitrogen excreted as percent of N intake	33.7	32.7	32.7	32.6
Total nitrogen excreted, g/day	402	413	419	434

Table 7. Effects of feeding increasing levels of reduced-oil DDGS to lactating dairy cows on lactation performance, rumen pH, rumen volatile fatty acid and ammonia production, apparent total tract digestibility of nutrients and fecal output (adapted from Benchaar et al., 2013)

	0% DDGS	10% DDGS	20% DDGS	30% DDGS
Total nitrogen excreted as percent of N intake	66.4	64.4	64.3	63.5
Milk nitrogen, g/day	177	187	185	189
Milk nitrogen as percent of N intake	29.4	29.1	28.2	27.7
Retained nitrogen, g/day	33	42	51	60
Retained nitrogen as percent of N intake	5.3	6.5	7.6	8.9
Productive nitrogen, g/day	204	229	236	248
Productive nitrogen as percent of N intake	34.6	35.6	35.7	36.5

[1]Energy-corrected milk = 0.327 × milk yield (kg/day) + 12.95 × milk fat yield (kg/day) + 7.2 × protein yield (kg/day)

[2]4 percent fat-corrected milk = 0.4 × milk yield (kg/day) + 15 × milk fat yield (kg/day)

Castillo-Lopez (2014) determined the effects of feeding increasing levels (0 to 30 percent) of reduced-oil DDGS (0 to 30 percent) to lactating cows on lactation performance, rumen fermentation, intestinal flow of microbial nitrogen and total-tract nutrient digestibility. Increasing diet inclusion rates of reduced-oil DDGS had no effect on milk yield and milk fat content, but tended to increase milk protein content (**Table 8**). Rumen pH was reduced by feeding increasing levels of reduced-oil DDGS, which may be partially attributed to lower TMR particle size and likely resulted in less time cows spent chewing to produce saliva and consequently had less buffering effect on rumen pH. Total ruminal volatile fatty acids and ammonia concentrations, as well as microbial nitrogen flow were not affected by DDGS feeding level. dry matter, organic matter, neutral detergent fiber and non-fiber carbohydrate digestibility tended to increase when feeding increasing amounts of reduced-oil DDGS. Results from this study indicate feeding up to 30 percent reduced-oil DDGS provides excellent lactation performance and milk composition without affecting rumen volatile fatty acid concentrations and microbial nitrogen supply and tends to increase apparent total tract digestibility of nutrients.

Table 8. Effects of feeding increasing levels of reduced-oil DDGS to lactating dairy cows on lactation performance, rumen pH, rumen volatile fatty acid and ammonia production, apparent total tract digestibility of nutrients and fecal output (adapted from Castillo-Lopez, 2014)

Measure	0% RO-DDGS	10% RO-DDGS	20% RO-DDGS	30% RO-DDGS
Body weight, kg	687	688	693	697
Body condition score	3.06	3.10	3.14	3.18
Dry matter intake, kg/day	25.0	23.8	25.9	27.9
Milk yield and composition				
Milk yield, kg/day	34.4	33.2	34.5	34.2
Milk fat %	3.59	3.74	3.64	3.67
Milk fat yield, kg/day	1.24	1.23	1.25	1.26
Milk protein %	3.08	3.18	3.15	3.19
Milk protein yield, kg/day	1.06	1.04	1.07	1.09
Milk lactose %	4.80	4.70	4.73	4.73

Table 8. Effects of feeding increasing levels of reduced-oil DDGS to lactating dairy cows on lactation performance, rumen pH, rumen volatile fatty acid and ammonia production, apparent total tract digestibility of nutrients and fecal output (adapted from Castillo-Lopez, 2014)

Measure	0% RO-DDGS	10% RO-DDGS	20% RO-DDGS	30% RO-DDGS
Milk lactose yield, kg/day	1.66	1.58	1.62	1.63
Milk urea nitrogen, mg/dL	16.24	15.54	16.23	15.94
Rumen pH				
Minimum	6.08	6.17	6.06	6.03
Maximum	6.95	8.88	6.83	6.77
Average	6.53	6.49	6.38	6.35
Time < 6.5, minutes/day	546	834	941	1,040
Area < 6.5, pH × minutes/day	126	158	357	334
Time< 6.3, minutes/day	279	382	936	946
Area < 6.3, pH × minutes/day	45	47	180	169
Volatile fatty acids				
Total, m*M*	136	135	139	131
Acetate, mol/100 mol	63.4	63.4	60.8	60.0
Propionate, mol/100 mol	22.1	22.0	25.0	26.1
Isobutyrate, mol/100 mol	0.8	0.8	0.7	0.7
Butyrate, mol/100 mol	11.2	11.2	10.6	10.7
Isovalerate, mol/100 mol	0.6	0.6	0.6	0.6
Valerate, mol/100 mol	1.8	1.9	2.1	2.2
Acetate:Propionate	2.98	2.94	2.52	2.39
Ammonia, mg/dL	19.0	18.8	19.3	17.6
Nutrient intake, apparent total tract digestibility, and fecal output				
Dry matter digestibility %	65.5	65.4	73.0	73.4
Fecal dry matter, kg/day	6.94	7.20	5.65	5.61
Organic matter intake, kg/day	19.6	19.9	20.0	19.3
Organic matter digestibility %	67.7	67.7	74.9	75.2
Non-fiber carbohydrate intake, kg/day	7.8	7.6	7.4	6.7
Non-fiber carbohydrate digestibility %	89.7	90.1	92.6	92.7
Neutral detergent fiber intake, kg/day	7.0	7.5	7.8	7.9
Neutral detergent fiber digestibility %	44.0	43.2	57.0	58.0
Nitrogen intake, kg/day	0.63	0.63	0.63	0.62
Nitrogen digestibility %	64.3	67.7	74.7	76.9
Fecal nitrogen, kg/day	0.20	0.20	0.15	0.15
Phosphorus intake, g/day	73	86	96	109
Phosphorus digestibility %	28.1	35.0	50.2	50.5
Fecal phosphorus, g/day	46	54	53	53

Ramirez-Ramirez et al. (2016) compared the effects of feeding diets containing 30 percent reduced-oil DDGS (6.6 percent crude fat), with and without 1.9 percent rumen-inert fat and 30 percent conventional high-oil DDGS (12.0 percent crude fat) on rumen fermentation, lactation performance and milk fat composition (**Table 9**). dry matter intake and milk yield was increased by feeding high-oil and reduced-oil DDGS sources. The increase in dry matter intake was likely a result of the 1.8 times greater proportion of fine particles (less than 1.18 mm) of diets containing DDGS when some of the forage was replaced. As a result, the volatile fatty acid composition of rumen fluid changed when DDGS diets were fed to reduce the concentration of acetate. Milk fat content and yield was reduced by feeding the high-oil DDGS source, but not the 30 percent reduced-oil DDGS diets compared with cows fed the control diet. The predominant bacterial species in the rumen were *Bacteroidetes* (54 percent) and *Firmicutes* (43 percent), with a few trends for changes in relative abundance of some bacterial families among dietary treatments. Feeding the DDGS diets resulted in greater polyunsaturated fatty acid intake and lower rumen pH compared with feeding the control diet with no DDGS, which may have been a result in greater fermentability of DDGS in the rumen and less chewing and saliva production during the rumination process. These changes in fermentation caused changes in bacterial biohydrogenation and the formation of conjugated linoleic acid (CLA isomers that suppress milk fat synthesis.) Although trans-10, cis-12 CLA is a known inhibitor of milk fat synthesis, it was only detected in milk from a few cows fed the high-oil DDGS diet, and was not detected in milk from cows fed the other dietary treatments. Furthermore, the concentration and yield of trans-10 18:1 in milk was almost 10 times greater in cows fed the DDGS diets compared with those fed the control diet. Therefore, feeding the reduced-oil DDGS diet appeared to reduce the ruminal supply and production of trans-10 18:1 which is associated with milk fat depression. Furthermore, although feeding the reduced-oil DDGS diet resulted in similar rumen pH compared with feeding the high-oil DDGS diet, there was no reduction in milk fat concentration or yield. This was likely a result of the lower oil content of the reduced-oil DDGS source compared with the conventional high-oil DDGS source. Results from this study showed feeding high-oil and reduced-oil DDGS increases dry matter intake and supported excellent milk production and milk composition even though diets were deficient in forage NDF. Although trans-10, cis-12 CLA was associated with reduced milk fat production, it was not observed when feeding the reduced-oil DDGS diets. Therefore, feeding diets containing 30 percent reduced-oil DDGS reduces the risk of milk fat depression.

Table 9. Effects of feeding total mixed rations containing 30 percent reduced-oil DDGS (6.6 percent crude fat), with or without rumen-inert fat, or 30 percent conventional high-oil DDGS (12 percent crude fat) to lactating dairy cows on lactation performance, milk composition, rumen fermentation, apparent total tract digestibility of nutrients (adapted from Ramirez-Ramirez et al., 2016)

Measure	0% DDGS	30% HO-DDGS	30% RO-DDGS	30% RO-DDGS+RIF
Body weight, kg	607[b]	619[a]	616[a]	619[a]
Body condition score	3.1	3.2	3.1	3.2
Dry matter intake, kg/day	21.6[b]	25.8[a]	26.1[a]	26.1[a]
Milk yield and composition				
Milk yield, kg/day	32.2[b]	33.8[a]	33.8[a]	34.0[a]
3.5% fat-corrected milk[1]	33.2[b]	32.8[b]	34.3[ab]	35.0[a]
Milk fat %	3.69[a]	3.27[b]	3.65[a]	3.70[a]
Milk fat yield, kg/day	1.18[a]	1.11[b]	1.22[a]	1.25[a]
Total fatty acids yield, g/day	1,103[a]	1,036[b]	1,137[a]	1,166[a]
Total unsaturated fatty acids, g/day	314[c]	400[a]	365[b]	398[a]
Total polyunsaturated fatty acids, g/ day	49	79	77	78
Total saturated fatty acids, g/day	787[a]	636[b]	765[a]	766[a]
18:1 trans-10	5.6[b]	18.9[a]	6.4[b]	7.6[b]
18:2 cis-9, trans-11	4.8[d]	13.7[a]	9.1[c]	11.0[b]
18:2 trans-10, cis-12	-	0.05	-	-
Milk protein %	3.07[c]	3.22[a]	3.21[a]	3.12[b]

Table 9. Effects of feeding total mixed rations containing 30 percent reduced-oil DDGS (6.6 percent crude fat), with or without rumen-inert fat, or 30 percent conventional high-oil DDGS (12 percent crude fat) to lactating dairy cows on lactation performance, milk composition, rumen fermentation, apparent total tract digestibility of nutrients (adapted from Ramirez-Ramirez et al., 2016)

	0% DDGS	30% HO-DDGS	30% RO-DDGS	30% RO-DDGS+RIF
Milk protein yield, kg/day	1.00[b]	1.10[a]	1.07[a]	1.06[a]
Milk urea nitrogen, mg/dL	15.3[b]	15.2[b]	16.4[a]	15.9[a]
Rumen fermentation				
pH	6.17[a]	5.80[b]	5.78[b]	6.02[ab]
Total volatile fatty acids, m*M*	116	121	127	119
Acetate, mol/100 mol	67.3[a]	60.9[c]	61.4[bc]	63.2[b]
Propionate, mol/100 mol	18.2[c]	23.6[a]	23.1[a]	20.7[b]
Isobutyrate, mol/100 mol	0.85	0.66	0.69	0.76
Butyrate, mol/100 mol	11.6	12.5	12.3	12.8
Isovalerate, mol/100 mol	0.56	0.56	0.51	0.62
Valerate, mol/100 mol	1.62[b]	1.84[ab]	2.00[a]	1.91[a]
Acetate:Propionate	3.74[a]	2.64[c]	2.68[bc]	3.05[b]
Ammonia, mg/dL	25.6	28.5	27.4	26.5
Apparent total tract nutrient digestibility				
Dry matter digestibility %	50.6[c]	58.0[b]	67.1[a]	59.1[b]
Organic matter digestibility %	52.6[c]	59.9[b]	69.3[a]	60.9[b]
Neutral detergent fiber digestibility %	32.5[c]	43.8[ab]	53.0[a]	43.2[b]
Nitrogen digestibility %	53.2[c]	63.8[b]	72.6[a]	64.4[b]

[1]3.5 percent fat-corrected milk = (milk fat, kg × 16.216) + (milk yield, kg × 0.4324)

Whelen et al. (2017) evaluated feeding a by-product mixture containing equal proportions (11.6 or 31 percent) of soybean hulls, DDGS and palm kernel extract to replace barley and soybean meal in diets for mid-lactation dairy cows grazing perennial ryegrass pasture. Results from this study showed barley and soybean meal can be replaced with soy hulls, DDGS and palm kernel meal without affecting milk production, digestibility and metabolic measures in dairy cows grazing ryegrass pasture.

Consumer satisfaction and health benefits of consuming milk

Several studies have shown feeding DDGS to lactating dairy cows increases the concentration of unsaturated fatty acids in milk, which can potentially lead to peroxidation and the development of off-flavors. Therefore, Testroet et al. (2015) determined the effects of feeding 0, 10, or 25 percent DDGS diets to lactating dairy cows on chemical composition and flavor characteristics of milk. Milk peroxides and free fatty acid content were low and almost all were below the detection limit. Results from this study indicate although feeding DDGS diets altered milk composition, it did not contribute to the development of off-flavors in milk.

In recent years, there has been tremendous interest in improving the human health benefits by increasing compounds with beneficial health effects in milk. One of these substances is cis-9, trans-11 conjugated linoleic acid (CLA), which has been shown to reduce the risk of carcinogenesis and atherosclerosis, and improve immunity. As a result, there have been several attempts to increase CLA content in milk through dietary changes. Anderson et al. (2006) and Sasikala-Appukuttan et al. (2008) showed that feeding diets containing 10 to 20 percent DDGS increased the CLA concentration in milk without affecting dry matter intake, milk yield and milk fat concentration. More recently, Kurokawa et al. (2013) fed diets containing 0, 10 or 20 percent DDGS diets with high neutral detergent fiber content (46 percent) to lactating dairy cows and confirmed feeding DDGS diets increased milk yield and markedly increased CLA content of milk. Therefore, it appears one of the added benefits of feeding DDGS to lactating dairy cows is an improvement in the human health benefits of consuming milk.

Feeding DDGS to Prepubertal Dairy Heifers

The majority of research on feeding DDGS to dairy cattle has focused on mature lactating dairy cows, with limited research on the effects on growth performance and long-term reproductive and lactation performance of dairy heifers. Although previous research has shown feeding DDGS improves reproductive performance of beef heifers (Martin et al., 2007; Engle et al., 2008), limited studies have been conducted with dairy heifers until recently. Anderson et al. (2015a,b) showed dairy heifers fed diets containing high amounts of reduced-oil DDGS (22 percent) and conventional high-oil DDGS (34 percent) had high ADG (0.96 kg/day) and apparent total tract digestibility of nutrients. Furthermore, Anderson et al. (2015b) showed energy status was maintained by feeding high DDGS diets based on similar plasma concentrations of leptin, IGF-1 and insulin, but feeding the high-oil DDGS diet increased plasma cholesterol and fatty acid concentations compared with feeding the reduced-oil DDGS diet. Increases in these plasma lipids may improve reproductive performance (Talavera et al., 1985; Thomas et al., 1997; Funston, 2004). To further evaluate these responses, Anderson et al. (2015c) determined reproductive performance, body measures and subsequent milk production and composition when fed diets containing a control diet based on corn and soybean products, 22 percent reduced-oil DDGS or 34 percent high-oil DDGS diets to 33 prepubertal dairy heifers for 24 weeks until calving, and subsequent four months of lactation. There were no differences in age at first service, number of inseminations, age at conception or calving (**Table 10**). Heifers fed the high-oil DDGS diet had less wither height and body length compared with those fed the control and reduced-oil DDGS diets. Heifers fed the reduced-oil DDGS diet had greater milk yield than those fed the other diets, and milk protein and fat content and yield were similar among dietary treatments. These results show feeding diets containing either high-oil or reduced-oil DDGS to replace corn and soybean products to prepubertal heifers maintains or enhances reproductive and lactation performance. Furthermore, dietary oil from DDGS can effectively replace starch from corn without detrimental effects on subsequent performance.

Table 10. Reproductive performance, body measures, lactation performance and milk composition of dairy heifers fed diets containing 22 percent reduced-oil DDGS and 34 percent high-oil DDGS for 24 weeks prepartum and four months of subsequent lactation (adapted from Anderson et al., 2015c)

Measure	0% DDGS	22% Reduced-oil DDGS	34% High-oil DDGS
Age at first service, days	394	400	398
No. artificial inseminations	2.11	2.89	1.78
Age at conception, days	455	483	444
Age at first calving, days	733	764	728
Body measurement, 3 weeks prepartum			
Body weight, kg	681	678	638
Withers height, cm	144[a]	144[a]	140[b]
Hip height, cm	147	147	144
Heart girth, cm	206	206	203
Body length, cm	145[a]	144[a]	140[b]
Body condition score	3.4	3.4	3.4
Body measure, at parturition			
Body weight, kg	634	621	590
Body condition score	3.3	3.1	3.2
Calf body weight, kg	40.8	41.6	41.6
No. calving problems	1	2	2
No. successfully transitioned	9	9	9

Table 10. Reproductive performance, body measures, lactation performance and milk composition of dairy heifers fed diets containing 22 percent reduced-oil DDGS and 34 percent high-oil DDGS for 24 weeks prepartum and four months of subsequent lactation (adapted from Anderson et al., 2015c)

	0% DDGS	22% Reduced-oil DDGS	34% High-oil DDGS
Age freshened, days	732	764	728
Milk yield, kg/day	33.0[b]	36.4[a]	34.7[ab]
Energy-corrected milk[1], kg/day	34.4	37.9	35.1
Milk protein %	2.94	3.01	3.03
Milk protein yield, kg/day	0.98	1.08	1.03
Milk fat %	3.98	3.94	3.86
Milk fat yield, kg/day	1.28	1.41	1.28
Somatic cells, × 10^3/mL	53.4	124.4	299.6

[a,b]Means within row with different superscripts are different (P less than 0.05)

[1]Energy-corrected milk = (0.327 × kg milk) + (12.95 × kg milk fat) + (7.2 × kg milk protein)

Additional studies have also shown consistent benefits of feeding high-oil and reduced-oil DDGS diets to growing dairy heifers. Suarez-Mena (2015) evaluated the effect of different forage-to-concentrate ratios (50:50 or 75:25) and DDGS inclusion rates (0, 7, 14 or 21 percent) on digestibility and rumen fermentation of precision-fed dairy heifer rations. Feeding the diet containing 14 percent DDGS resulted in the highest apparent digestibility of dry matter, organic matter, acid detergent fiber and neutral detergent fiber, but nitrogen retention decreased with increasing diet inclusion rate of DDGS. Molar concentrations of acetate tended to decrease when feeding the high forage diet and as dietary DDGS levels increased, whereas propionate concentrations increased as DDGS levels increased. Furthermore, rumen protozoa count decreased as dietary DDGS level increased. These results indicate feeding diets containing 14 percent DDGS improved nutrient utilization and fermentation in dairy heifers fed diets with different forage-to-concentrate ratios.

Manthey and Anderson (2016) fed dairy heifers either a DDGS or a corn-soybean meal concentrate at 0.8 percent of body weight along with ad libitum access to grass hay on dry matter intake and growth performance. dry matter intake, body weight, ADG and gain:feed were similar between dietary treatments, and there were no differences in hip height, heart girth, hip width and body condition scores. These results indicate heifers fed DDGS at 0.8 percent of body weight with ad libitum access for grass hay had similar growth performance and skeletal frame growth as those fed equal amounts of the corn-soybean meal concentrate and grass hay. In a subsequent study, Manthey et al. (2016) showed limit-feeding diets containing increasing concentrations of DDGS (up to 50 percent) improved gain:feed, apparent total tract digestibility of dry matter and crude protein, while maintaining body frame growth without increasing body condition score.

Manthey and Anderson (2017) conducted two additional studies to determine the effects of limit-feeding peripubertal dairy heifers diets containing DDGS with different forage-to-concentrate ratios (Experiment 1), and feeding DDGS with ad libitum grass hay (Experiment 2), on growth, rumen fermentation, nutrient digestibility, metabolic profile, onset of puberty and subsequent performance. In Experiment 1, Holstein heifers were fed 30 percent (2.65 percent of body weight), 40 percent (2.50 percent of body weight), or 50 percent (2.35 percent of body weight) DDGS, with the remainder of the diet consisting of grass hay and mineral mix. In the second experiment, heifers were fed either a corn-soybean meal or a DDGS concentrate mix (0.8 percent of body weight) and provided ad libitum access to grass hay. Results from these studies showed DDGS can be used to replace up to 50 percent of hay in limit fed diets, or can replace corn and soybean meal when providing ad libitum access to hay, to support satisfactory growth performance, with some changes in metabolic profiles but improvement in nutrient digestibility.

Manthey et al. (2017) also determined the effects of feeding distillers dried grains (30, 40 or 50 percent) in replacement of forage in limit-fed dairy heifer rations on the metabolic profile and onset of puberty. Plasma glucose, insulin, IGF-1, leptin and triglycerides were similar among treatments, but total fatty acids and polyunsaturated fatty acids increased with increasing dietary levels of DDGS. Heifer age and body weight at puberty were not different among dietary treatments. These results showed that feeding increasing dietary inclusion rates of DDGS (up to 50 percent) maintains body energy status without accumulating excess adipose tissue and has no detrimental effects on age or body weight at puberty.

Lastly, Rodriguez-Hernandez (2017) determined if the type and concentration of glucosinolates in carinata meal affected feed preference and intake compared with feeding DDGS or other oilseed meals in dairy heifers. Heifers had the greatest preference for diets containing DDGS, followed by linseed meal, camilina meal and canola meal, with the least preference for carinata meal.

Conclusions

Corn DDGS is an excellent source of energy, protein and phosphorus for lactating dairy cows. Numerous studies have shown corn DDGS can be included in lactating dairy cow diets at levels up to 20 percent, without decreasing dry matter intake, milk production and milk fat and protein content. In fact, inclusion of 20 to 30 percent DDGS supports milk production equal to or greater than diets with no DDGS, without a reduction in milk fat concentration if rations are properly formulated. Furthermore, adding 30 to 50 percent DDGS to developing dairy heifer diets supports excellent growth, reproductive and subsequent lactation performance. Kalscheur et al. (2012b) provided recommended diet inclusion rates of DDGS for dairy cattle and calves in various stages of production and identified key dietary components that need to be managed when formulating DDGS diets (**Table 11**).

Table 11. Recommended maximum diet inclusion rates of DDGS for dairy cattle (adapted from Kalscheur et al. 2012b)

Production stage	DDGS %	Critical nutrients in diet formulation
Pre-weaned calves	25	Lysine, fiber, crude fat
Growing heifers	30	Crude fat/energy, sulfur
Dry cows	15	Crude fat/energy, sulfur, calcium/phosphorus
Lactating cows	20	Total fat/polyunsaturated fatty acids, physically effective fiber, sulfur, calcium/phosphorus, RUP, lysine

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