Chapter 8
Nutritional Characteristics and Feeding Value of Dried Corn Bran and Solubles, De-oiled (Solvent Extracted DDGS), and Corn Distillers Oil in Animal Diets

Introduction

In addition to corn fermented protein (CFP; Chapters 1, 2, 3, 4, and 5), high-protein distillers dried grains without solubles (HP-DDG) described in Chapter 6, and corn protein concentrate (CPC) described in Chapter 7, several other new corn co-products are being produced by a few ethanol plants using new industrial processes that result in different nutritional profiles and feeding applications. These include wet and dried corn fiber/bran and solubles (CBS), de-oiled DDGS, and corn distillers oil (CDO). Therefore, the purpose of this chapter is to provide current nutritional profiles of each co-product category, describe the benefits and limitations for their use in diets for different animal species, and provide summaries of feeding trials that have been conducted.

Dried Corn Bran and Solubles

Nutritional composition of corn bran and solubles for ruminants

A few ethanol plants that use ICM's Fiber Separation Technology™ are producing high moisture (40% dry matter) CBS. Because of the high moisture content affecting transportation costs, this co-product is not exported but has been evaluated in beef feedlot cattle diets. See the section in this chapter that contains a brief summary of results from feeding trials that have evaluated high moisture corn bran and distillers solubles in beef feedlot cattle diets.

Nutritional composition of dried corn bran and solubles for swine

New corn ethanol facilities in Brazil are using ICM's Fiber Separation Technology™ to produce dried CBS for use in swine, poultry, and cattle diets. Paula et al. (2021) determined the digestible energy (DE), metabolizable energy (ME), standardized ileal digestibility (SID) of amino acids, and standardized total tract digestibility (STTD) of phosphorus (P) in dried CBS compared with conventional sources of DDGS and HP-DDG produced in the U.S., and a HP-DDG source produced using ICM's Fiber Separation Technology™ in Brazil. As expected, the crude protein (CP) content of CBS is relatively low (13.87%), and the ether extract (9.00%) and neutral detergent fiber (NDF; 39.07%) content is relatively high compared with the other corn co-products evaluated (**Table 1**). The ME content of CBS was about 91% of the ME content in U.S. DDGS, and 80% and 71% of the ME content in U.S. HP-DDG and Brazilian HP-DDG, respectively. Although the P content of CBS (0.71%) was greater than found in the other corn co-products, the STTD of P was the lowest (46.4%) of the co-products compared (**Table 1**). The SID of lysine (Lys), methionine (Met), threonine (Thr), and tryptophan (Trp) in CBS were lower than for the other corn co-products. These results indicate that dried CBS has substantially less ME and digestible amino acid content than conventional sources of DDGS and HP-DDG produced in the U.S., and HP-DDG produced in Brazil. However, this nutritional profile would be suitable for use in sow gestation diets where limiting energy intake is necessary to control body condition, and the requirements for digestible amino acids are relatively low.

Table 1. Chemical composition (as-fed basis) of U.S. corn dried distillers grains with solubles (DDGS) and high-protein distillers dried grains (HP-DDG) compared with Brazilian HP-DDG and dried corn bran with solubles (CBS; adapted from Paula et al., 2021)

Analyte	**U.S. DDGS**	**U.S. HP-DDG**	**Brazil HP-DDG**	**Brazil CBS**
Dry matter, %	86.08	89.62	92.30	87.59
Crude protein, %	26.37 (72)	34.83 (62)	42.93 (67)	13.87 (59)
Ether extract, %	6.40	7.80	10.30	9.00
NDF, %	36.59	47.48	37.40	39.07
ADF, %	14.31	19.81	17.53	13.31
Gross energy, kcal/kg	4,532	4,915	5,296	4,513
DE (swine), kcal/kg	3,134	3,352	4,060	2,843
ME (swine), kcal/kg	2,941	3,116	3,757	2,680
Ash, %	4.89	3.39	2.81	4.80
Ca, %	0.04	0.02	0.02	0.02
P, %	0.68	0.46	0.48	0.71
STTD P, %	62.7	67.6	48.3	46.4
Mg, %	0.28	0.18	0.01	0.33
Na, %	0.44	0.47	0.09	0.24
K, %	1.09	0.63	0.41	1.50
Cu, mg/kg	14.26	7.9	7.10	7.14
Fe, mg/kg	59.56	52.1	112.5	87.32
Mn, mg/kg	12.72	9.00	9.97	16.81
Zn, mg/kg	63.39	56.40	75.55	61.26
Indispensable amino acids, %				
Arg	1.10 (84)	1.50 (76)	2.06 (83)	0.69 (74)
His	0.64 (72)	0.89 (66)	1.26 (76)	0.36 (69)
Ile	0.98 (67)	1.46 (68)	1.79 (76)	0.46 (65)
Leu	2.90 (74)	4.38 (72)	5.30 (81)	1.20 (72)
Lys	0.73 (55)	1.00 (53)	1.37 (66)	0.40 (46)
Met	0.43 (75)	0.54 (75)	0.95 (82)	0.25 (73)
Phe	1.21 (72)	1.86 (72)	2.16 (78)	0.54 (64)
Thr	0.95 (68)	1.32 (67)	1.66 (76)	0.51 (54)
Trp	0.15 (74)	0.22 (71)	0.23 (73)	0.11 (66)
Val	1.30 (66)	1.82 (69)	2.37 (76)	0.64 (65)
Dispensable amino acids, %				
Ala	1.86 (78)	2.65 (72)	3.28 (82)	0.90 (79)
Asp	2.02 (65)	2.72 (64)	3.29 (73)	1.02 (53)
Cys	0.59 (70)	0.80 (72)	1.09 (82)	0.34 (59)
Glu	4.34 (75)	6.21 (70)	7.98 (81)	2.03 (69)
Gly	1.08 (94)	1.40 (73)	1.77 (93)	0.66 (80)
Pro	2.14 (59)	3.08 (43)	3.99 (55)	1.08 (52)

Ser	1.20 (66)	1.74 (64)	2.18 (79)	0.61 (63)
Tyr	1.09 (69)	1.45 (70)	1.91 (79)	0.49 (62)
Total amino acids	24.44 (62)	34.76 (65)	44.39 (68)	12.16 (65)
Lys:CP	2.77	2.87	3.19	2.88

Previous studies by Anderson et al. (2012) and Rochell (2011) determined the nutrient profile, DE and ME content for swine, and the AME_n content of a similar dried CBS source for poultry (**Table 2**). Although there are no recent studies that have estimated AME_n in CBS for poultry, the DE (3,282 kcal/kg DM) and ME (3,031 kcal/kg DM) content of CBS for swine determined by Anderson et al. (2012) were almost identical to the DE (3,246 kcal/kg DM) and ME (3,060 kcal/kg DM) content for CBS determined by Paula et al. (2021). Although the amino acid content of CBS differed between the Anderson et al. (2012) and Paula et al. (2021) studies, the P content was similar.

Table 2. Published values (dry matter basis) of nutritional composition of corn bran and solubles for swine and poultry (adapted from Anderson et al., 2012, and Rochell et al., 2011)

Analyte, % DM basis	**Corn bran + solubles**
Dry matter	90.82
Gross energy, kcal/kg	4,982
DE (swine), kcal/kg	3,282
ME (swine), kcal/kg	3,031
AME_n (poultry), kcal/kg	3,030
Crude protein	34.74
Ether extract	9.68
TDF	26.65
NDF	25.21
ADF	5.35
Ash	5.31
Ca	0.03
P	0.76
Indispensable amino acids	
Arg	0.77
His	0.44
Ile	0.50
Leu	1.30
Lys	0.62
Met	0.23
Phe	0.55
Thr	0.61
Trp	0.09
Val	0.76
Dispensable amino acids	
Ala	1.04
Asp	1.02
Cys	0.30
Glu	1.95
Gly	0.77
Pro	1.08

Ser	0.65
Tyr	0.41

Summary of corn bran and solubles feeding trials for ruminants

Garland et al. (2019a) conducted a study to compare energy and nutrient digestibility of diets containing corn (control), 20 and 40% HP-DDG, 40% corn bran plus solubles (CBS), and 40% conventional wet distillers grains with solubles (WDGS) and dried distillers grains with solubles (DDGS) of dry matter (DM) intake. Feeding CBS resulted in lower digestibility of DM and organic matter (OM), equivalent neutral detergent fiber (NDF) digestibility, but greater acid detergent fiber (ADF) digestibility and digestible energy than cattle fed corn. Dry matter and OM digestibility and digestible energy in CBS was similar to that of the conventional WDGS and DDGS co-products. In addition, DM, OM, NDF, ADF digestibility, as well as digestible energy at the 40% diet inclusion rate of CBS were similar to feeding HP-DDG. These results indicate that although feeding HP-DDG and CBS resulted in reduced DM and OM digestibility, energy intake was increased when these co-products were included in the diet. Furthermore, CBS has comparable feeding value with WDGS and DDGS.

In a subsequent study, Garland et al. (2019b) compared feeding diets containing 20% or 40% of DM intake using wet CBS with feeding diets containing 20% or 40% of DM intake using wet distillers grains (WDG) to finishing steers on growth performance and carcass characteristics. Feed intake and feed conversion increased with increasing diet inclusion rate of either corn co-product, and ADG was greater when feeding the CBS or WDG diets compared with feeding the control diet which consisted of high moisture and dry rolled corn. Results from this study showed that feeding wet CBS at the same diet inclusion rates as WDG resulted in similar growth performance and carcass characteristics.

Garland et al. (2019c) also compared feeding diets containing 40% of DM intake from HP-DDG, conventional DDGS, WDGS, and wet CBS on growth performance and carcass characteristics of crossbred steers. There were no differences in feed intake among dietary treatments, but cattle fed HP-DDG and wet CBS had greater ADG and carcass weight than steers fed the WDGS and DDGS diets. Based on feed conversion observed in finishing steers in this trial, the feeding values of HP-DDG and wet CBS were estimated to be 121% and 125% the feeding value of corn, respectively.

De-oiled (solvent extracted) DDGS

De-oiled DDGS is a co-product (NovaMeal) produced using solvent extraction to remove corn oil from DDGS, but limited quantities are currently being produced in the U.S. However, this may change in the future as a result of increasing demand for fats and oils to produce renewable diesel in the U.S. Almost all of the current de-oiled DDGS being produced is used in diets for lactating dairy cows. Therefore, most of the research on nutritional composition and feeding value has focused on it feeding value for lactating dairy cows.

AAFCO Definition

The Association of American Feed Control Officials defines deoiled corn distillers dried grains with solubles as follows:

27.9 Deoiled Corn Distillers Dried Grains with Solubles, Solvent Extracted, is the product resulting from the solvent extraction of oil from corn distillers dried grains with solubles (DDGS) to result in a crude fat content of less than 3% on an as fed basis. It is intended as a source of protein. The label shall include a guarantee for minimum crude protein and maximum sulfur. The words "solvent extracted" are not required when listing as an ingredient in a manufactured feed."

Nutritional composition of de-oiled DDGS for ruminants

Mjoun et al. (2010c) evaluated and compared the nutrient composition, rumen degradable and undegradable protein and intestinal digestibility of amino acids in conventional solvent extracted soybean meal (SBM), high-oil DDGS, de-oiled DDGS, and HP-DDG for lactating Holstein dairy cows (**Table 3**). The rate of degradation of slowly degradable protein was greatest for SBM (11.8%/hr) to 2.7%/hr for de-oiled DDGS. Rumen undegradable protein ranged from 32% for SBM to 60% for de-oiled DDGS. Although total digestible protein was greater for SBM than distillers co-products, they all exceeded 95%. Similarly, the intestinal digestibility of most amino acids in distiller's co-products exceeded 92%, which was slightly less than for SBM (>94%), except for Lys digestibility which was 84 to 87% in distillers co-products compared with 96% digestibility in SBM. Intestinal absorbable dietary protein was greater in de-oiled DDGS (55%) compared with DDGS (48%) and HP-DDG (51%), which was also greater than in SBM (31%). These results indicate that protein and amino acid digestibility of de-oiled DDGS and other corn co-products are comparable to those in soybean meal when fed to lactating dairy cows.

Table 3. Comparison of chemical composition, rumen degradable and undegradable protein and intestinal digestibility of amino acids in lactating dairy cows (adapted from Mjoun et al., 2010c)

Analyte, % DM basis	Soybean meal	DDGS	De-oiled DDGS	HP-DDG
Dry matter	90.2	88.5	87.7	93.2
Crude protein (CP)	49.6	30.8	34.0	41.5
Soluble protein, % of CP	15.0	14.0	10.9	6.4
Rumen degradable protein, % of CP	68	48	40	46
Rumen undegradable protein, % of CP	32	52	60	54
Estimated intestinal protein digestibility, % of RUP	97	92	91	94
Intestinally absorbable dietary protein, % of CP	31	48	55	51
Total digestible dietary protein, % of CP	99	96	95	97
NDICP, % of CP	3.4	9.1	19.7	10.1
ADICP, % of CP	3.2	8.8	13.2	9.9
NDF	12.0	31.5	42.5	30.4
ADF	6.2	9.4	12.4	10.5
Ether extract	1.1	10.6	3.5	3.2
Starch	2.0	8.9	5.1	8.3

NFC	29.9	22.7	14.7	22.5
Ash	7.4	4.4	5.3	2.4
Ca	0.70	0.06	0.07	0.06
P	0.73	0.75	0.77	0.51
Mg	0.33	0.32	0.34	0.16
K	2.34	0.92	0.93	0.53
S	0.42	0.62	0.74	0.79
Indispensible amino acids, g/kg CP[1]				
Arg	71.0 [85] (99)	47.4 [66] (93)	46.9 [59] (93)	37.1 [57] (93)
His	27.9 [87] (96)	30.0 [71] (93)	30.5 [65] (93)	27.7 [68] (93)
Ile	48.0 [84] (98)	40.4 [65] (93)	43.1 [59] (93)	41.8 [56] (93)
Leu	79.7 [84] (98)	117.4 [59] (96)	125.3 [50] (96)	135.3 [51] (96)
Lys	64.7 [86] (96)	34.8 [77] (84)	32.2 [69] (86)	29.5 [70] (87)
Met	14.3 [82] (94)	20.4 [55] (95)	19.9 [37] (95)	20.4 [48] (94)
Phe	50.2 [84] (98)	45.2 [53] (95)	47.3 [45] (95)	50.9 [49] (95)
Thr	38.2 [83] (98)	37.8 [63] (88)	38.0 [51] (90)	36.5 [56] (91)
Val	50.0 [83] (97)	53.0 [67] (92)	53.4 60] (92)	51.4 [59] (92)
Dispensable amino acids, g/kg CP				
Ala	43.3	69.3	71.2	73.1
Asp	114.3	63.7	68.5	65.0
Cys	14.7	19.3	18.1	18.3
Glu	149.9	130.4	143.8	160.8
Gly	42.9	41.1	41.1	32.6
Pro	47.8	86.3	74.3	88.0
Ser	43.3	40.7	43.1	43.6
Total amino acids	918.1 [84]	877.0	896.9	912.0

[1]Values in [ ] are ruminal degradation (%) of indispensable amino acids and values in ( ) are intestinal digestibility (%) of indispensable amino acids from RUP

Nutritional composition of de-oiled DDGS for swine

Two studies have been conducted to determine the DE and ME content (Jacela et al., 2011; Anderson et al. 2012), and one study has estimated the standardized ileal digestibility (SID) of amino acids (Jacela et al., 2011) in de-oiled DDGS for swine (**Table 4**). Although the gross energy of de-oiled DDGS sources evaluated in these studies was comparable, the DE and ME content directly determined by Anderson et al. (2012) was much greater than the *in vivo* determined DE content and calculated ME content by Jacela et al. (2011). Jacela et al. (2011) used the Noblet and Perez (1993) and Noblet et al. (1994) equations to estimate ME and NE content, respectively, of de-oiled DDGS, but the accuracy of this approach is questionable because these equations were derived and are intended to be used for complete feeds, not individual ingredients. Regardless, the DE and ME values for de-oiled DDGS are comparable to those obtained for reduced oil DDGS in recent studies (Paula et al., 2021; Yang et al., 2021). The SID coefficients of amino acids determined by Jacela et al. (2011) are also comparable to those observed for reduced oil DDGS sources from recent studies (Paula et al., 2021; Yang et al., 2021), but no estimates are available for the STTD of P in de-oiled DDGS for swine.

Table 4. Published values of nutritional composition of de-oiled DDGS for swine		
Analyte, % DM basis	**De-oiled DDGS (Jacela et al., 2011)**	**De-oiled DDGS (Anderson et al., 2012)**

Dry matter	87.69	87.36
Gross energy, kcal/kg	5,098	5,076
Digestible energy, kcal/kg	3,100	3,868
Metabolizable energy, kcal/kg	2,858[1]	3,650
Net energy, kcal/kg	2,045[2]	-
Crude protein	35.58	34.74
Ether extract	4.56	3.15
TDF	-	37.20
NDF	39.46	50.96
ADF	18.36	15.82
Ash	5.29	5.16
Ca	0.06	0.08
P	0.87	0.84
Indispensable amino acids		
Arg	1.50 (83)[3]	1.44
His	0.93 (75)	0.89
Ile	1.38 (75)	1.25
Leu	4.15 (84)	4.12
Lys	0.99 (50)	1.00
Met	0.67 (80)	0.64
Phe	1.92 (81)	1.51
Thr	1.26 (69)	1.26
Trp	0.22 (78)	0.18
Val	1.75 (74)	1.76
Dispensable amino acids		
Ala	2.43 (79)	2.48
Asp	2.10 (65)	2.19
Cys	0.62 (67)	0.61
Glu	4.85 (79)	5.43
Gly	1.35 (65)	1.39
Pro	2.41 (88)	2.54
Ser	1.48 (77)	1.58
Tyr	1.29 (82)	1.22

[1]Calculated as ME = 1 × DE – 0.68 × CP (Noblet and Perez, 1993).

[2]Calculated as NE = (0.87 × ME) – 442 (Noblet et al., 1994).

[3]Values in parentheses are standardized ileal digestibility coefficients determined for each amino acid.

Nutritional composition of deoiled DDGS for poultry

The same source of de-oiled DDGS evaluated by Anderson et al. (2012) for swine, was also used to determine the AME_n content for broilers by Rochell et al. (2011). Therefore, the nutrient profile for de-oiled DDGS shown in **Table 4**, represents the same de-oiled DDGS source which contained 2,146 kcal/kg AME_n for poultry (Rochell et al., 2011).

Summary of feeding trials evaluating de-oiled DDGS in lactating dairy cow diets

Mjoun et al. (2010a) conducted a study to determine the optimal concentration of de-oiled DDGS in mid-lactation Holstein cow diets during an 8-week feeding trial. Diets contained 0, 10, 20, and 30% de-oiled DDGS to replace soybean-based ingredients on a DM basis. Results of this study showed no differences in diet inclusion rate of de-oiled DDGS on DM intake and milk production (**Table 5**). Milk fat percentage and yield increased linearly with increasing dietary levels of de-oiled DDGS, while milk protein concentration was affected quadratically with no effect on milk protein yield from feeding increasing dietary levels of de-oiled DDGS. The efficiency of milk production tended to increase linearly, but the efficiency of N utilization for milk production was not affected by increasing dietary levels of de-oiled DDGS. These results indicate that feeding up to 30% de-oiled DDGS diets to lactating dairy cows provides similar performance to cows fed control diets contain soy-based co-products as protein and energy sources.

Table 5. Dry matter intake, milk yield, and milk composition of mid-lactation dairy cows fed 0, 10, 20, and 30% de-oiled DDGS to replace soybean feed ingredients in diets (Mjoun et al., 2010a)

	Dietary inclusion rate of de-oiled DDGS (% of DMI)			
Measure	**0%**	**10%**	**20%**	**30%**
Body weight, kg	705	713	721	710
Body weight change, g/d	-167	15	230	-36
Body condition score[1]	3.56	3.37	3.36	3.53
Net energy intake[2], Mcal/d	34.7	37.0	38.3	35.2
Net energy for maintenance[3], mcal/d	10.9	11.2	11.0	11.0
Net energy required for milk[4], Mcal/d	22.6	24.0	24.7	25.0
Energy balance[5], Mcal/d	3.18	1.60	2.80	-0.81
Energy efficiency[6]	64.6	66.8	64.2	71.2
Dry matter intake, kg/d	22.7	23.0	23.7	22.2
Crude protein intake, kg/d	4.0	4.1	4.2	4.0
Milk production, kg/d	34.5	34.8	35.5	35.2
Energy corrected milk production[7], kg/d	32.6	34.6	35.6	36.0
Fat corrected milk production[8], kg/d	30.0	31.7	32.1	33.1
Feed efficiency[9]	1.47	1.53	1.49	1.61
N efficiency[10]	25.5	27.0	25.8	26.0
Milk composition				
Fat, %	3.18	3.40	3.46	3.72
Fat yield, kg/d	1.08	1.19	1.23	1.32
Protein, %Ash	2.99	3.06	3.13	2.99
Protein yield, kg/d	1.03	1.07	1.10	1.06
Lactose, %	4.95	4.96	4.94	5.06
Lactose yield, kg/d	1.71	1.74	1.75	1.76
Total solids, %	12.10	12.39	12.40	12.67
Total solids, kg/d	4.15	4.35	4.43	4.45

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

[2]Net energy required for lactation (Mcal/kg) × dry matter intake (kg/d).

[3]Net energy for maintenance = body weight$^{0.75}$ × 0.08
[4]Net energy required for milk = milk yield (kg) × [(0.0929 × fat %) + (0.0563 × protein %) + (0.0395 × lactose %)]
[5]Energy balance = net energy intake – (net energy for maintenance + net energy for lactation).
[6]Energy efficiency = net energy for lactation/net energy intake.
[7]Energy corrected milk = [0.327 × milk yield (kg)] + [12.95 × fat yield (kg)] + [7.2 × protein yield (kg)].
[8]Fat corrected milk = [0.4 × milk yield (kg)] + [15 × fat yield (kg)].
[9]Feed efficiency = energy corrected milk/dry matter intake.
[10]Nitrogen efficiency = milk N (kg/d)/N intake (kg/d).

Mjoun et al. (2010b) also compared the lactation responses of early lactation dairy cows fed diets containing no distillers co-products (control with soybean meal, expeller soybean meal, and soybean hulls), 22% conventional DDGS, or 20% de-oiled DDGS for a 14-week trial. Diets were formulated to contain similar CP, ether extract, NDF and net energy for lactation concentrations. There were no differences in body weight, body weight change, body condition score, DM intake, milk yield, milk fat, and milk lactose content among dietary treatments (**Table 6**). However, milk protein concentration and yield were similar between cows fed the DDGS and de-oiled DDGS diets but greater than in cows fed the control diet. Feed efficiency tended to be greater, and nitrogen efficiency was greater in cows fed the DDGS and de-oiled DDGS diets compared with those fed the control diet. These results indicate that feeding diets containing 20% de-oiled DDGS to dairy cows in early lactation results in equal or improved lactation performance and milk composition compared with feeding soy-based diets.

Table 6. Milk production, composition, and nutritional efficiency of feeding early-lactation dairy cows diets containing soy products (control), 22% DDGS, and 20% de-oiled DDGS (Mjoun et al., 2010b)

Measure	Control	22% DDGS	20% De-oiled DDGS
Initial body weight, kg	693	682	660
Final body weight, kg	734	722	704
Body weight change, kg/d	0.47	0.47	0.53
Body condition score[1]	3.43	3.32	3.34
Net energy intake[2], Mcal/d	41.3	40.1	40.3
Net energy for maintenance[3], mcal/d	11.0	11.0	11.0
Net energy required for milk[4], Mcal/d	26.4	26.5	27.4
Energy balance[5], Mcal/d	4.39	1.98	1.98
Energy efficiency[6]	63.1	66.9	68.1
Dry matter intake, kg/d	24.8	24.7	24.6
Crude protein intake, kg/d	4.3	4.3	4.3
Milk production, kg/d	39.2	38.9	39.8
Energy corrected milk production[7], kg/d	38.0	37.8	39.5
Fat corrected milk production[8], kg/d	35.7	35.3	37.1
Feed efficiency[9]	1.50	1.57	1.61
N efficiency[10]	24.5[b]	26.9[a]	26.5[a]
Milk composition			
Fat, %	3.63	3.24	3.57

Fat yield, kg/d	1.33	1.34	1.40
Protein, %	2.82[b]	2.88[a]	2.89[a]
Protein yield, kg/d	1.07[b]	1.15[a]	1.14[a]
Lactose, %	4.90	4.99	4.96
Lactose yield, kg/d	1.94	1.94	1.96
Total solids, %	12.3	12.0	12.4
Total solids, kg/d	4.73	4.70	4.90

[1]Body condition score: 1 = emaciated to 5 = obese.
[2]Net energy required for lactation (Mcal/kg) × dry matter intake (kg/d).
[3]Net energy for maintenance = body weight$^{0.75}$ × 0.08
[4]Net energy required for milk = milk yield (kg) × [(0.0929 × fat %) + (0.0563 × protein %) + (0.0395 × lactose %)]
[5]Energy balance = net energy intake – (net energy for maintenance + net energy for lactation).
[6]Energy efficiency = net energy for lactation/net energy intake.
[7]Energy corrected milk = [0.327 × milk yield (kg)] + [12.95 × fat yield (kg)] + [7.2 × protein yield (kg)].
[8]Fat corrected milk = [0.4 × milk yield (kg)] + [15 × fat yield (kg)].
[9]Feed efficiency = energy corrected milk/dry matter intake.
[10]Nitrogen efficiency = milk N (kg/d)/N intake (kg/d).
[a,b] Means within rows with uncommon superscripts are difference ($P < 0.05$).

Summary of feeding trials evaluating diets containing deoiled DDGS for nursery and growing-finishing pigs

Jacela et al. (2011) conducted two feeding trials to evaluate the effects of increasing dietary levels (0, 5, 10, 20, and 30%) of de-oiled DDGS in diets for nursery pigs (initial BW = 9.9 kg) for a 28-day feeding period on growth performance (**Table 7**), and to growing-finishing pigs (initial BW = 30 kg) for a 99-day feeding period on growth performance and carcass characteristics (**Table 8**). Diets were formulated to contain equal ME content by adding increasing amounts of soybean oil as de-oiled DDGS levels increased, and equal SID lysine content based on determined values obtained from previous experiments. During the grower-finisher trial, a 4-phase feeding program was used. As shown in **Table 7**, the were no differences in growth performance of nursery pigs between dietary treatments, indicating that feeding diets containing up to 30% de-oiled DDGS to nursery pigs provided acceptable growth performance when supplemental energy from soybean oil was provided to maintain dietary ME density. However, increasing de-oiled DDGS levels in diets fed to growing-finishing pigs resulted in a linear decrease in average daily gain (ADG), average daily feed intake (ADFI), carcass weight, and carcass yield (**Table 8**). However, gain efficiency tended to be improved with no effects on carcass backfat, percentage lean, and fat-free lean index as dietary inclusion rate of de-oiled DDGS increased (**Table 8**). It is unclear why reductions in ADG and ADFI occurred during the growing-finishing trial and not during the nursery trial when it is more likely for these negative responses to be observed.

Table 7. Effects of increasing dietary inclusion rates of de-oiled DDGS in diets for nursery pigs on growth performance during a 28-day feeding period (adapted from Jacela et al., 2011)

	Dietary deoiled DDGS inclusion rate, %				
Measure	**0**	**5**	**10**	**20**	**30**

Initial BW, kg	10.0	10.0	9.6	9.9	9.9
Final BW, kg	22.7	22.8	22.2	22.4	22.3
ADG, kg	0.455	0.459	0.452	0.445	0.442
ADFI, kg	0.749	0.771	0.760	0.751	0.761
G:F	0.609	0.595	0.594	0.593	0.582

Table 8. Effects of increasing dietary inclusion rates of de-oiled DDGS in growing-finishing pig diets on growth performance during a 99-day feeding period and carcass characteristics (adapted from Jacela et al., 2011)

Measure	Dietary deoiled DDGS inclusion rate, %				
	0	**5**	**10**	**20**	**30**
Initial BW, kg	29.6	29.6	29.6	29.6	29.6
Final BW[1], kg	121.4	119.3	118.8	118.2	116.2
ADG[1], kg	0.909	0.893	0.887	0.887	0.873
ADFI[1], kg	2.16	2.17	2.11	2.11	2.04
G:F[2]	0.420	0.413	0.422	0.421	0.431
Carcass weight[1], kg	91.1	89.0	89.1	87.7	86.3
Carcass yield[1], %	75.5	75.0	75.0	74.7	74.3
Backfat, mm	16.46	16.53	16.53	16.38	16.96
Loin depth[3], mm	63.5	62.2	62.5	63.0	60.7
Carcass lean, %	56.48	55.91	56.30	56.43	55.78
Carcass fat-free lean index	50.4	50.4	50.4	50.5	50.2

[1]Linear reduction ($P < 0.01$) with increasing dietary levels of deoiled DDGS.
[2]Trend ($P < 0.10$) of a linear improvement with increasing dietary levels of deoiled DDGS.
[3]Trend ($P < 0.10$) of a linear reduction with increasing dietary levels of deoiled DDGS.

Corn Distillers Oil

AAFCO Definition

The Association of American Feed Control Officials defines corn distillers oil as follows:

> "33.10 ____ Distillers Oil, Feed Grade, is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture and mechanical or solvent extraction of oil by methods employed in the ethanol production industry. It consists predominantly of glyceride esters of fatty acids and contains no additions of free fatty acids or other materials from fats. It must contain, and be guaranteed for, not less than 85% total fatty acids, not more than 2.5% unsaponifiable matter, and not more than 1% insoluble impurities. Maximum free fatty acids and moisture must be guaranteed. If an antioxidant(s) is used, the common or usual name must be indicated, followed by the words "used as a preservative." If the product bears a name descriptive of its kind of origin, i.e., "corn, sorghum, barley, rye," it must correspond thereto with the predominating grain declared as the first word in the name." Proposed 2015, Adopted 2016 rev. 1)

Corn distillers oil (CDO) is produced in large quantities by the U.S. ethanol industry and is used in renewable diesel production and as a supplemental energy source in swine and poultry diets.

The ME content of CDO is comparable to that in crude degummed soybean oil, which is due to its high concentrations of polyunsaturated fatty acids (PUFA), especially linoleic acid. As a result of the high PUFA content in CDO, it is highly susceptible to oxidation when exposed to thermal processes, oxygen, and transition metals (Cu and Fe). Therefore, the addition of antioxidants may be necessary to prevent oxidation during transport and storage because oxidized lipids can have adverse effects on health and growth performance of pigs and broilers when included in diets (Hung et al., 2017). In addition, adding CDO to corn-soybean meal grower-finisher diets increases the PUFA content of pork carcass fat which reduces firmness and shelf-life stability.

Chemical composition of corn distillers oil

One of the distinguishing features of CDO compared with refined corn oil is that CDO sources have greater free fatty acid (FFA) content (**Table 9**), which can range from less than 2% FFA to as much as 18% FFA. Previous studies evaluating various feed lipids have shown that increasing FFA content reduces ME content for pigs and poultry, which led to the development of DE (swine) and AME_n (poultry) prediction equations (Wiseman et al., 1998). Corn oil is distinguishable from other lipid sources because of its relatively high polyunsaturated acid (PUFA) content, especially oleic (9c-18:1; 28 to 30% of total lipid) and linoleic (18:2n-6; 53 to 55% of total lipid) acid content. Vegetable oils have greater PUFA content than animal fats, which results in vegetable oils having greater ME content (Kerr et al., 2015). As a result, CDO contains one of highest ME concentrations of all feed fats and oils, but it is also more susceptible to peroxidation (Kerr et al., 2015; Shurson et al., 2015; Hanson et al., 2015). Feeding peroxidized lipids to pigs and broilers has been shown to reduce growth rate, feed intake, and gain efficiency (Hung et al., 2017), and highly peroxidized corn oil reduces efficiency of energy utilization and antioxidant status in nursery pigs (Hanson et al., 2016). However, the addition of commercially available antioxidants to distillers corn oil are effective in minimizing peroxidation of CDO when stored at high temperature and humidity conditions (Hanson et al., 2015). Although the extent of peroxidation (peroxide value, anisidine value, and hexanal) in CDO is somewhat greater than in refined corn oil, it is much less than in the peroxidized corn oil fed in the nursery pig study by Hanson et al. (2016), where reductions in growth performance were observed.

Table 9. Chemical composition and peroxidation measures of refined corn oil and corn distillers oil (CDO) sources (adapted from Kerr et al., 2016)

Measurement	**Refined corn oil**	**CDO (4.9% FFA[1])**	**CDO (12.8% FFA)**	**CDO (13.9% FFA)**
Moisture, %	0.02	1.40	2.19	1.19
Insolubles, %	0.78	0.40	1.08	0.97
Unsaponifiables, %	0.73	0.11	0.67	0.09
Ether extract, %	99.68	99.62	98.96	99.63
Free fatty acids, %	0.04	4.9	12.8	13.9
Fatty acids, % of total lipids				
Palmitic (16:0)	11.39	13.20	11.87	13.20
Palmitoleic (9c-16:1)	0.10	0.11	0.11	0.11
Margaric (17:0)	0.07	0.07	0.07	0.07
Stearic (18:0)	1.83	1.97	1.95	1.97

Oleic (9c-18:1)	29.90	28.26	28.92	28.26
Linoleic (18:2n-6)	54.57	53.11	54.91	53.11
Linolenic (18:3n-3)	0.97	1.32	1.23	1.32
Nonadecanoic (19:0)	ND[2]	0.65	0.65	0.65
Arachidic (20:0)	0.40	0.39	0.39	0.39
Gonodic (20:1n-9)	0.25	0.24	0.24	0.24
Behenoic (22:0)	0.13	0.13	0.12	0.13
Lignoceric (24:0)	0.17	0.19	0.18	0.19
Other fatty acids	0.21	0.41	ND	0.41
Peroxidation measures				
Peroxide value, MEq/kg	1.9	2.9	3.3	2.0
Anisidine value[3]	17.6	80.9	70.3	73.3
Hexanal, µg/g	2.3	4.4	3.9	4.9

[1]FFA = free fatty acids.
[2]ND = not detected.
[3]There are no units for anisidine value.

Metabolizable energy content of corn distillers oil for swine and poultry

Kerr et al. (2016) determined the DE and ME content of refined corn oil (0.04% FFA) and 3 sources of commercially produced CDO with FFA content ranging from 4.9 to 13.9% for use in swine diets, and AME_n content of the same sources in broiler diets. As shown in **Table 10**, the ME content (swine) of CDO samples ranged from 8,036 to 8,828 kcal/kg, with the 4.9% FFA CDO sample containing similar ME content compared with refined corn oil. The ME values for refined corn oil (8,741 kcal/kg), 4.9% FFA CDO (8,691 kcal/kg), and 13.9% FFA CDO (8,397 kcal/kg) were similar to the value of 8,570 kcal/kg for corn oil reported in NRC (2012). Except for the 12.8% FFA CDO source having the lowest ME content of all sources, there was no significant detrimental effect of FFA content on DE or ME content of CDO for swine. For broilers, the AME_n content was not different among the CDO sources, which ranged from 7,694 to 8,036 kcal/kg (**Table 10**), and were not different than the AME_n content of refined corn oil (8,072 kcal/kg). However, these values were substantially less than the AME_n values for refined corn oil (9,639 to 10,811 kcal/kg) reported in NRC (1994). Ether extract digestibility was not different for nursery pigs or broilers fed the different sources of CDO with variable FFA content. Kerr et al. (2106) also reported that the use of the Wiseman et al. (1998) equations over-estimated the DE content (swine) in refined corn oil and the 12.8% and 13.9% FFA CDO sources but provided a similar estimate of DE content for the 4.9% FFA CDO source. However, these equations over-estimated AME_n content of all corn oil sources by 379 to 659 kcal/kg for broilers. These results suggest that new DE and AME_n prediction equations need to be developed that are more accurate and specific for CDO for both swine and broilers but indicate that CDO containing up to 14% FFA can serve as an excellent supplemental energy source in swine and broiler diets.

Table 10. In vivo determined DE and ME content of refined corn oil and distillers corn oil (CDO) sources with variable free fatty acid (FFA) content for nursery pigs and broilers (adapted from Kerr et al., 2016)

Measurement	Refined corn oil	CDO (4.9% FFA[1])	CDO (12.8% FFA)	CDO (13.9% FFA)
GE, kcal/kg	9,423	9,395	9,263	9,374
DE (swine), kcal/kg	8,814[a]	8,828[a]	8,036[b]	8,465[ab]
ME (swine), kcal/kg	8,741[a]	8,691[a]	7,976[b]	8,397[ab]
EE[2] digestibility (swine), %	93.2	94.0	91.7	95.0
AME_n[3] (poultry), kcal/kg	8,072	7,936	8,036	7,694
EE digestibility (poultry), %	91.6	89.8	89.0	88.4
UFA:SFA[4]	6.13	5.00	5.61	5.00

[a,b]Means with uncommon superscripts within rows are different ($P < 0.05$).
[1]FFA = free fatty acids.
[2]EE = ether extract.
[3]AME_n = nitrogen-corrected apparent metabolizable energy.
[4]UFA = unsaturated fatty acids; SFA = saturated fatty acids.

Conclusions

Corn bran and solubles is currently produced in a wet form by a limited number of ethanol plants and has historically been used exclusively in beef cattle feedlots diets as an energy source to replace of corn co-products, high moisture corn, and dry-rolled corn. Availability of dried CBS with lower transportation costs could provide the opportunity for greater use in a larger variety of ruminant diets, including dairy cattle. The relatively low ME, digestible amino acid content of dried CBS would have limited feeding value in swine and poultry diets if it were to be produced and available in significant quantities. Dried de-oiled (solvent extracted) DDGS is produced in limited quantities and marketed under the brand name of NovaMeal. De-oiled DDGS is best suited for use in lactating dairy cow diets where is can be fed up to 20% of DM intake to provide improved milk production and composition compared with feeding soy-based diets. Although studies have shown that de-oiled DDGS can be added to nursery diets to support acceptable growth performance, its use in growing-finishing swine diets requires dietary energy and digestible amino acid supplementation to achieve optimal growth performance. Corn distillers oil (CDO) is an excellent supplemental energy source in swine and poultry diets. The FFA content of CDO can be as high as 14% and does not appear to affect the ME content for swine, but this FFA concentrations appears to reduce ME content of CDO for broilers. However, with the tremendous demand for feed fats and oils for renewable diesel production in the U.S., the future availability of CDO may be limited in the export market.

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