Chapter 6
Nutritional Characteristics and Feeding Value of High-Protein DDG(S) Sources in Animal Feeds

Introduction

Except for conventional distillers dried grains with solubles (DDGS), more research studies have been conducted to evaluate the nutritional value and animal responses from feeding high-protein distillers grains without solubles (HP-DDG) sources than any other corn co-product produced by the U.S. ethanol industry. Unfortunately, HP-DDG is also the most confusing category of all corn co-products in the market today because it has been and continues to be produced using a wide variety of technologies that result in substantially different nutrient profiles among sources. The term “high-protein” DDG was first introduced around 2006-2007 as a way of differentiating new corn co-products that contained 36 to 48% crude protein (CP) from conventional DDGS sources containing 27 to 30% CP. These new corn co-products were produced using various fractionation processes which concentrated the protein by removing a portion of corn fiber and oil. Although HP-DDG is a distinctly different category of corn co-products than DDGS, it is often confused with corn fermented protein (CFP) co-products which also contain high concentrations of CP (>50%). However, while some CFP co-product sources contain similar CP content compared with some HP-DDG sources, the processes used to produce CFP result in greater estimated spent yeast content (20 to 27%) compared with HP-DDG sources, that likely contain about 0 to 18% spent yeast. Unfortunately, corn co-product producers, marketers, and researchers have not carefully described and used appropriate terminology when communicating information about these co-products in research publications, websites, presentations, technical brochures, and product specifications sheets. Therefore, nutritionists are cautioned to be aware of the significantly different nutrient profiles among various HP-DDG sources that have been produced and evaluated in animal feeding trials during the previous 15 years when using data from various published references. Be sure to contact your supplier to ensure that you have received the most accurate information.

Fractionation process technology used to produce HP-DDG has evolved dramatically since 2005. A summary of published animal feeding studies evaluating HP-DDG sources that were produced using older front-end fractionation processes, the majority of which are no longer used today, is shown in **Table 1**. All HP-DDG sources currently being produced use ICM, Inc. FST™ technology. While results from these studies may be useful for providing a general indication of the relative feeding value of HP-DDG for various animal species, they do not accurately represent the nutritional composition, digestibility, and feeding applications of the HP-DDG sources currently being produced by a few U.S. ethanol plants. To emphasize this point, **Table 2** provides a summary of the nutrient profiles and digestibility coefficients of HP-DDG sources for swine evaluated in recent publications compared with the nutrient profile in NRC (2012), which is based on older front-end fractionation technology and publications listed in **Table 1**. Note that NRC (2012) value for CP content is greater, while values for ether extract and phosphorus are less than all other HP-DDG sources produced using new fractionation processes (**Table 2**).

For example, the nutritional profile of HP-DDG from the swine NRC (2012) shown in **Table 2**, is representative of the HP-DDG sources evaluated in many of the studies listed in **Table 1**. Note that in comparison with the nutritional profile of HP-DDG sources that have been evaluated in recent studies using new production technologies, the CP content was relatively high (45%) while the crude fat content was relatively low (3.5%). However, because of the high variability in nutrient content, energy value, and amino acid and phosphorus digestibility, it is essential to know your source and use nutritional profiles specific to that source for accurate diet formulation.

Table 1. Summary of published studies evaluating HP-DDG sources produced using older process technologies that are no longer used today

Species	**Reference**
Swine	Widmer et al. (2007, 2008)
	Gutierrez et al. (2009a,b)
	Kim et al. (2009)
	Jacela et al. (2010)
	Seabolt et al. (2010)
	Anderson et al. (2012)
	Adeola and Ragland (2012)
	Adeola and Ragland (2016)
	Peterson et al. (2014)
	Rojo et al. (2016)
Poultry	Batal (2007)
	Kim et al. (2008, 2010)
	Applegate et al. (2009)
	Jung and Batal (2009, 2010)
	Rochell et al. (2011)
	Tangenjaja and Wina (2011)
Aquaculture	Barnes et al. (2012a,b)
	Øverland et al. (2013)
	Prachom et al. (2013)
	Herath et al. (2016a,b)
Dairy cows	Mjoun et al. (2009)
	Christen et al. (2010)
	Maxin et al. (2013a,b)
	Swanepoel et al. (2014)

Nutritional Composition and Digestibility of Current HP-DDG Sources

Swine

Most of the published studies that have determined the energy and amino acid digestibility of HP-DDG sources have been conducted in swine (**Table 2**). Because of the various types of production technologies used to produced HP-DDG, the composition among sources can be highly variable with CP levels ranging from 34-43%, lysine (Lys) from 1.0-1.4%, and standardized ileal digestibility (SID) of Lys from 47-76%. Furthermore, gross energy (GE) can range from 4,813-5,296 kcal/kg and digestible energy (DE) content ranging from 3,352-4,424 kcal/kg. Surprisingly, the phosphorus content (0.40-0.50%) is less variable than DE and amino acid concentrations among HP-DDG sources, but the limited estimates of standardized total tract digestibility (STTD) of phosphorus are more variable ranging from 48-68% (**Table 2**). The SID of amino acids is also highly variable among HP-DDG source and generally range from 60-89%, with the exception of Lys where SID ranges for most sources between 47-66%. These results indicate that HP-DDG producers need to determine specific energy, digestible amino acids, and digestible phosphorus values for their products for various animal species and provide this information to their customers to optimize economic and nutritional value of this ingredient in practical feed formulations.

Table 2. Comparison of chemical composition (as-fed basis), energy, amino acid, and phosphorus digestibility of branded and unbranded high-protein distillers dried grains (HP-DDG) sources for swine from recently published studies

Analyte	NRC (2012)[1]	Rho et al. (2017)[2]	Rho et al. (2017)[2]	Paula et al. (2021)[3]	Paula et al. (2021)[4]	Espinosa and Stein (2018)[5]	Lee and Stein (2021)[6]
Dry matter, %	91.20	91.9	91.3	89.62	92.30	86.50	87.45
Crude protein, %	45.35	38.9 (61)[7]	39.4 (73)	34.83 (62)	42.93 (67)	37.11 (77)	39.05 (76)
Ether extract, %	3.54	9.27	8.63	7.80	10.30	*	8.50**
Acid hydrolyzed ether extract, %	*	*	*	*	*	7.59	8.46
Neutral detergent fiber, %	33.63	29.4	28.4	47.48	37.40	31.87	*
Acid detergent fiber, %	20.63	14.6	14.8	19.81	17.53	14.68	*
Total dietary fiber, %	*	*	*	*	*	34.20	37.6
Soluble dietary fiber, %	*	*	*	*	*	2.40	2.2
Insoluble dietary fiber, %	*	*	*	*	*	31.80	35.4
Gross energy, kcal/kg	5,173	4,986	4,935	4,915	5,296	4,825	4,813
Digestible energy, kcal/kg	4,040	4,130	4,157	3,352	4,060	4,424	3,688
Metabolizable energy, kcal/kg	3,732	*	*	3,116	3,757	4,275	3,496
Ash, %	2.39	2.40	2.34	3.39	2.81	2.41	1.80
Ca, %	0.02	0.05	0.06	0.02	0.02	*	< 0.10**
P, %	0.36	0.50	0.47	0.46	0.48	*	0.40**
STTD of P, %	73	*	*	68	48	*	*
Mg, %	0.09	*	*	0.18	0.01	*	*
Na, %	0.06	*	*	0.47	0.09	*	*
K, %	0.37	*	*	0.63	0.41	*	*
Cu, mg/kg	2.03	*	*	7.9	7.10	*	*
Fe, mg/kg	65.30	*	*	52.1	112.5	*	*
Mn, mg/kg	7.00	*	*	9.00	9.97	*	*
Zn, mg/kg	27.30	*	*	56.40	75.55	*	*
Indispensable amino acids, %							
Arg	1.62 (85)	1.64 (72)	1.66 (79)	1.50 (76)	2.06 (83)	1.63 (87)	1.59 (84)
His	1.07 (79)	1.01 (66)	1.04 (72)	0.89 (66)	1.26 (76)	0.97 (82)	1.00 (75)
Ile	1.83 (80)	1.48 (68)	1.50 (75)	1.46 (68)	1.79 (76)	1.59 (82)	1.53 (75)
Leu	6.18 (86)	4.78 (81)	5.01 (84)	4.38 (72)	5.30 (81)	4.39 (89)	4.92 (86)
Lys	1.22 (69)	1.19 (47)	1.20 (56)	1.00 (53)	1.37 (66)	1.43 (76)	1.34 (62)
Met	0.93 (86)	0.79 (79)	0.82 (83)	0.54 (75)	0.95 (82)	0.70 (87)	0.84 (83)
Phe	2.42 (84)	2.01 (77)	2.07 (80)	1.86 (72)	2.16 (78)	2.03 (86)	2.00 (80)

Thr	1.59 (75)	1.45 (60)	1.46 (67)	1.32 (67)	1.66 (76)	1.39 (75)	1.52 (72)
Trp	0.24 (82)	-	-	0.22 (71)	0.23 (73)	0.30 (80)	0.42 (81)
Val	2.12 (78)	1.92 (69)	1.95 (75)	1.82 (69)	2.37 (76)	2.07 (81)	1.89 (73)
Dispensable amino acids, %							
Ala	3.32 (82)	2.78	2.87	2.65 (72)	3.28 (82)	2.58 (85)	2.83 (80)
Asp	2.75 (74)	2.62	2.60	2.72 (64)	3.29 (73)	2.44 (73)	2.64 (73)
Cys	0.82 (78)	0.73	0.78	0.80 (72)	1.09 (82)	0.69 (75)	0.80 (70)
Glu	7.52 (83)	6.69	6.92	6.21 (70)	7.98 (81)	5.61 (88)	6.83 (82)
Gly	1.39 (70)	1.44	1.43	1.40 (73)	1.77 (93)	1.45 (71)	1.38 (65)
Pro	3.65 (79)	3.29	3.40	3.08 (43)	3.99 (55)	-	3.26 (92)
Ser	1.96 (82)	1.89	1.93	1.74 (64)	2.18 (79)	1.46 (82)	1.94 (82)
Tyr	1.92 (85)	-	-	1.45 (70)	1.91 (79)	1.46 (87)	1.59 (86)
Total amino acids	-	-	-	34.76 (65)	44.39 (68)	35.11 (83)	38.45 (80)
Lys:CP	2.69	3.06	3.05	2.87	3.19	3.85	3.43

[1]Data from National Research Council (2012) for swine.
[2]Data from Rho et al. (2017) for two high-protein distillers dried grains samples produced using Fiber Separation Technology™ developed by ICM, Inc., Colwich, KS.
[3]Data from Paula et al. (2021) for high-protein distillers dried grains produced by Corn Plus Co-op (Winnebago, MN, USA) using Fiber Separation Technology™ developed by ICM, Inc., Colwich KS
[4]Data from Paula et al. (2021) for high-protein distillers dried grains produced by FS Bioenergia, Inc. (Lucas do Rio Verde, MT, Brazil) using Fiber Separation Technology™ developed by ICM, Inc., Colwich, KS.
[5]Data from Espinosa and Stein (2018) for high-protein distillers dried grains produced by Lincolnway Energy (Nevada, IA) using mechanical separation of fiber based on solublility before fermentation, oil extraction after fermentation, and low heat compression drying.
[6]Unpublished data from Lee and Stein (2021) provided with permission from The Andersons, Maumee, OH. High-protein distillers dried grains (ANDVantage™ 40Y) produced by using Fiber Separation Technology™ developed by ICM, Inc., Colwich, KS.
[7]Values in parentheses are standardized ileal digestibility coefficients for the corresponding amino acid.
*No data were provided.
**Values obtained from supplier nutrient specification sheets.

As shown in **Table 3**, HP-DDG contains relatively low amounts of starch (2.3%) and high concentrations of neutral detergent fiber (NDF; 41.3%) and total dietary fiber (39.7%), which is similar to conventional DDGS. Because of the relatively high concentrations of fiber in DDGS and HP-DDG, swine and poultry nutritionists have evaluated the addition of various commercially available carbohydrases and proteases in DDGS diets (Jang et al., 2021), which may provide similar responses in HP-DDG diets based on similar physiochemical attributes such as swelling and water-binding capacity (**Table 3**). Boucher et al. (2021) evaluated the effects of adding a multi-carbohydrase enzyme blend (xylanase, glucanase, cellulase, amylase, invertase, and protease) to diets containing DDGS and HP-DDG for swine to determine if they were effective in improving DE and metabolizable energy (ME) content of the diets. The HP-DDG source was produced using mechanical separation technology (ICM, Inc., Colwich, KS, USA) to remove large non-fermentable fiber particles prior to fermentation to increase throughput and ethanol production. However, the nutrient profile reported for this HP-DDG source reported in this study does not reflect the typical composition of HP-DDG produced using ICM, Inc. FST technology because of lower crude protein and greater fiber content. This may be an example of researchers using incorrect terminology or misunderstanding the process used to produce the corn co-product being evaluated. Regardless, the results showed that compared with DDGS, this HP-DDG source had about 50% less starch, 20% more protein, 14% greater water-binding capacity, and greater DE (3,896 and 4,405 kcal/kg DM, respectively) and ME (3,494 and 3,872 kcal/kg DM, respectively) content for swine, but the multi-carbohydrase enzyme was ineffective in improving DE and ME values in both DDGS and HP-DDG diets.

Table 3. Chemical and physiochemical characteristics of corn and co-products (adapted from Boucher et al., 2021)

Characteristic	Corn	DDGS	HP-DDG	Dried Corn Bran + Solubles
Chemical composition				
Dry matter, %	86.1	89.3	88.9	94.9
Gross energy, kcal/kg	3,769	4,600	4,950	4,629
Crude protein, %	6.5	27.1	32.5	19.4
Ether extract, %	2.7	7.6	9.6	6.8
Starch, %	67.1	4.5	2.3	7.4
Total dietary fiber, %	11.2	36.7	39.7	37.0
NDF, %	12.3	30.5	41.3	33.5
ADF, %	3.2	7.1	15.1	7.6
Physiochemical attributes				
Bulk density, g/L	522	507	478	386
Swelling, L/kg	2.4	3.5	3.6	4.4
Water-binding capacity, g/g	2.1	2.9	3.3	2.9

Poultry

Fries-Craft and Bobeck (2019) determined the nitrogen-corrected apparent metabolizable energy (AME_n) and SID of amino acids of a HP-DDG source for broilers (**Table 4**). Compared with a conventional DDGS source, HP-DDG had greater CP (34.1%), AME_n (2,725 kcal/kg), and amino acid content, with relatively high SID of amino acid coefficients ranging from 81% for Lys, threonine (Thr), and cysteine (Cys) to 90% for arginine (Arg) and leucine (Leu). Unpublished data for ANDVantage™ 40Y (provided with permission from The Andersons) showed greater CP and amino acid content than reported in the Fries-Craft study, but comparable amino acid digestibility coefficients (**Table 4**). The TME_n content of ANDVantage™ 40Y was also substantially greater than found in a conventional DDGS source.

Table 4. Nutrient content, nitrogen-corrected apparent metabolizable energy (AME_n) and true metabolizable energy (TME_n), and standardized ileal digestibility of amino acids (as-fed basis) of high-protein distillers dried grains (HP-DDG) sources for broilers (adapted from Fries-Craft and Bobeck, 2019)

Analyte	DDGS[1]	HP-DDG[1]	ANDVantage™40Y[2]
Dry matter, %	89.80	83.10	90.0

Crude protein, %	27.10	34.10	40.4
Ether extract, %	9.63	7.91	8.50
Crude fiber, %	7.85	8.35	8.80
AME_n, kcal/kg	2,629	2,725	NR[4]
TME_n, kcal/kg	2,509	NR	3,286
Arg	1.10	1.49 (90)[3]	1.69 (93)[3]
His	0.62	0.88 (86)	1.15 (88)
Ile	1.15	1.26 (84)	1.65 (87)
Leu	2.40	4.32 (90)	4.93 (94)
Lys	0.70	1.16 (81)	1.35 (81)
Met	0.50	0.74 (89)	0.80 (91)
Phe	1.35	1.57 (88)	2.11 (91)
Thr	0.93	1.31 (81)	1.56 (85)
Trp	0.20	0.30 (82)	0.30 (88)
Val	1.40	1.60 (86)	1.97 (87)
Ala	NR	NR (86)	NR
Asp	NR	NR (82)	NR
Cys	0.45	0.58 (81)	NR
Glu	NR	NR (90)	NR
Gly	0.60	1.25 (NR)	NR
Pro	NR	NR (82)	NR
Ser	1.30	1.60 (87)	NR
Tyr	0.80	1.34 (84)	NR
Lys:CP	2.58	3.40	3.34

[1]Published data from Fries-Craft and Bobeck (2019)
[2]Unpublished data provided with permission from The Andersons, Maumee, OH.
[3]Values in parentheses are standardized ileal digestibility coefficients of amino acids.
[4]NR = not reported

Aquaculture

A recent study compared the nutritional differences between HP-DDG (ANDVantage™ 40Y), SBM (SBM), and poultry meal, and the effects of replacing increasing amounts of SBM or poultry meal with HP-DDG in channel catfish diets (Nazeer et al., 2022). A comparison of the nutritional profiles of these three ingredients is shown in **Table 5**. Poultry meal contains greater CP and indispensable amino acid content than HP-DDG except for Leu. Similarly, SBM contains greater concentrations of amino acids than HP-DDG except for Leu and methionine (Met). Therefore, supplementation of synthetic Lys, Met, Thr, and tryptophan (Trp) is likely necessary when partially substituting poultry meal and SBM with HP-DDG in aquaculture diets to support optimal growth performance and fillet composition.

Table 5. Comparison of the nutrient content (as-fed basis) of poultry meal, SBM, and high-protein distillers dried grains (HP-DDG; adapted from Nazeer et al, 2002)

Analyte, %	Poultry meal	SBM	ANDVantage™40Y[2]
Dry matter	91.05	88.52	90.86
Crude protein	64.59	46.66	42.25
Ether extract	12.29	0.48	8.48
Crude fiber	-	3.59	7.05

Ash	9.88	6.47	2.13
Indispensable amino acids			
Arg	4.32	3.49	1.84
His	1.41	1.24	1.18
Ile	2.64	2.27	1.88
Leu	4.55	3.64	5.48
Lys	4.11	3.02	1.30
Met	1.22	0.61	0.86
Phe	2.57	2.38	2.34
Thr	2.55	1.83	1.58
Trp	0.60	0.64	0.34
Val	3.21	2.31	2.30
Indispensable amino acids			
Ala	4.05	2.04	3.19
Asp	5.29	5.31	2.86
Cys	0.77	0.69	0.83
Glu	8.58	9.00	7.17
Gly	5.54	2.00	1.56
Hydroxylysine	0.23	0.02	0.00
Hydroxyproline	1.55	0.11	0.07
Pro	3.59	2.21	3.44
Ser	2.53	2.26	1.82
Taurine	0.47	0.12	0.10
Tyr	2.15	1.73	1.79

Summary of Swine HP-DDG Feeding Trials

Yang et al. (2019) evaluated the use of experimentally determined ME and SID values of amino acids for HP-DDG (37.6%) produced by Lincolnway Energy (Nevada, IA) in nursery pig diets. Weaned pigs were fed a common phase 1 diet for the first week after weaning, followed by 1 of 4 diets containing 0, 10, 20, or 30% HP-DDG during phase 2 (days 7-21 post-weaning) and phase 3 (days 21-42 post-weaning). Diets were formulated to contain equivalent concentrations of ME, digestible Lys, Met, Thr, and Trp, and digestible phosphorus. As dietary HP-DDG levels increased, calculated SID Leu to Lys ratios increased from 119 to 173% in phase 2 diets, and from 120 to 160% in phase 3 diets. Similarly, SID isoleucine (Ile) to Lys ratios ranged from 60 to 69% in phase 2 diets and 54 to 59% in phase 3 diets, while SID valine (Val) to Lys ratios ranged from 63 to 79% in phase 2 and from 64 to 68% in phase 3 diets. A linear reduction in average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G:F) was observed during phase 2 and 3 as diet inclusion rates of HP-DDG increased. Although pigs in this study were challenged with *Streptococcus suis* and *Escherichia coli*, there was no difference in morbidity among treatments, but including HP-DDG in the diets tended to reduce mortality compared with feeding the control diets with no HP-DDG. These results indicate that the linear reduction in growth performance observed from adding increasing dietary levels of this HP-DDG source were likely due to an overestimation of the SID amino acid content, antagonistic effects of excess digestible dietary Leu content relative to digestible Val and Ile content and increasing dietary fiber content which may have increased Thr requirements.

Similarly, Cemin et al. (2019b) conducted a study to determine the effects of feeding increasing amounts (0, 10, 20, 30, or 40%) of HP-DDG produced using ICM, Inc. Fiber Separation Technology in nursery pig diets and to estimate the productive energy content of HP-DDG. Net energy (NE) content of HP-DDG was estimated using three different DE prediction equation approaches. Caloric efficiency was calculated by multiplying ADFI by the kcal of estimated net energy per kg of diet and dividing by ADG. For the overall 21-day feeding period, feeding diets containing increasing levels of HP-DDG resulted in linear decreases in ADG, ADFI, and final body weight. There was a quadratic effect for feed:gain (F:G) with the best response observed when 40% HP-DDG diets were fed. As a result, the caloric efficiency of HP-DDG was linearly reduced as dietary levels increased, and the approach used to apply DE prediction equations underestimated the NE content of HP-DDG. Based on the caloric efficiency calculations, the NE of this HP-DDG source was estimated to be about 97% of the NRC (2012) value of NE content in corn.

Two experiments were conducted to determine the effects of feeding 30% HP-DDG diets in 4-phase feeding programs to growing-finishing pigs on growth performance, carcass characteristics, and pork fat quality (Yang et al., 2020). The first experiment used a HP-DDG source from IGPC Ethanol, Inc. (Alymer, Ontario, Canada) which contained relatively low concentrations of deoxynivalenol (DON; 1.7 mg/kg), total fumonisins (FUM; 0.60 mg/kg), and zearalenone (ZEA; 0.2 mg/kg). The second experiment evaluated a source of HP-DDG obtained from ICM, Inc. (St. Joseph, MO) that also contained relatively low concentrations of DON (1.0 mg/kg), FUM (3.80 mg/kg), and ZEA (0.06 mg/kg). Guidelines for “safe” maximum concentrations of DON (< 1 mg/kg), FUM (5 mg/kg), and ZEA (< 1 mg/kg) suggested that no negative effects on growth performance would be expected when HP-DDG was added at levels of 30% of the total diet. Results from experiment 1 showed that feeding the 30% HP-DDG diets with low concentrations of DON, FUM, and ZEA resulted in reduced ADG and ADFI during the first 8 weeks of the 16-week feeding trial compared with feeding corn-SBM control diets. To determine if this reduction in growth rate and feed intake was due to excess Leu in HP-DDG diets or the low concentrations of mycotoxins, a commercial mycotoxin mitigation product was added to both the control and 30% HP-DDG diets for half of the pigs in the trial, while the other half of these pigs continued to be fed diets without the mycotoxin mitigant for the remaining 8 weeks of the overall 16-week feeding period. The addition of the mycotoxin mitigant to diets was effective in restoring growth performance of pigs fed the HP-DDG diets to be comparable to pigs fed the control diets. These results indicate that the reduction in growth performance during the first 8 weeks of the feeding period was a result of the additive negative effects of low concentrations of DON, FUM, and ZEA and not excess Leu in the diets.

For the second experiment, a mycotoxin mitigation product was added to the diets at the beginning of the feeding period. Results showed that pigs fed the 30% HP-DDG diets had reduced ADG, final body weight, ADFI, and G:F during the 16-week feeding period (**Table 6**). Furthermore, feeding the 30% HP-DDG diets resulted in reduced hot carcass weight, carcass yield, loin muscle area, and percentage of fat-free carcass lean but did not affect backfat thickness compared with pigs fed the control diets (**Table 6**). Pigs fed the HP-DDG diets also had greater polyunsaturated fatty acid content and iodine value of pork fat than pigs fed the corn-SBM control diets indicating that carcass pork fat was less firm when feeding the HP-DDG diets. These results indicate that 1) low concentrations of mycotoxins in diets containing contaminated HP-DDG can reduce growth performance, but effective mitigation additives can alleviate these negative effects, 2) excess Leu in 30% HP-DDG diets interferes with the utilization of Ile and Val resulting in suboptimal feed intake, growth, gain efficiency, and carcass lean, and 3) the high unsaturated fatty acid content of corn oil present in HP-DDG when used at a 30% diet inclusion reduces carcass pork fat firmness.

Table 6. Growth performance and carcass characteristics of growing-finishing pigs fed 30% high-protein distillers dried grains (HP-DDG) diets with a mycotoxin mitigation agent (adapted from Yang et al., 2020)

Measure	Control		30% HP-DDG + MA	
Initial BW, kg	22.75		22.74	
Final BW, kg	133.37[a]		126.58[b]	
ADG, kg	1.01[a]		0.95[b]	
ADFI, kg	2.63[a]		2.57[b]	
G:F	0.41[a]		0.39[b]	
Carcass characteristics	**Gilt**	**Barrow**	**Gilt**	**Barrow**
Hot carcass weight[1], kg	98.34	98.16	96.07	95.86
Carcass yield[1], %	75.55	75.33	74.04	73.78
Backfat depth[2], mm	19.75	23.45	20.72	23.22
Loin muscle area[1,2,3], cm	49.26	44.91	42.58	43.71
Fat-free lean[1,2,3], %	52.40	49.38	50.10	49.04

[a,b] Means within rows with uncommon superscripts are different ($P < 0.05$).
[1]Diet effect ($P < 0.01$).
[2] Sex effect ($P < 0.05$).
[3] Diet × sex interaction ($P < 0.01$).

The most recent study evaluating diets containing increasing levels of HP-DDG was conducted by Rao et al. (2021). Growth performance and carcass composition responses were compared between growing-finishing pigs fed increasing dietary levels (0, 15, and 30%) of conventional DDGS or HP-DDG (ICM, Inc.). All diets were formulated to contain equal digestible Lys content but different levels of NE. Dietary branched-chain amino acid ratios were adjusted based on the equation from Cemin et al. (2019) to account for excess Leu in DDGS and HP-DDG diets. Caloric efficiency was calculated by dividing estimated NE intake by weight gain (Cemin et al., 2020). Results showed that increasing diet inclusion rate of conventional DDGS significantly decreased final body weight linearly, while increasing dietary HP-DDG inclusion rates tended to decrease final body weight (**Table 7**). These decreases in final body weight were a result of linear decreases in ADG during the grower phase when feeding increasing dietary amounts of either DDGS or HP-DDG. Pigs fed the HP-DDG diets had greater ADFI and G:F than pigs fed the DDGS diets. Hot carcass weight and carcass yield were linearly reduced as dietary inclusion rates of DDGS or HP-DDG increased. Iodine value was calculated as an estimate of the unsaturated to saturated fatty acid ratio in carcass fat and linearly increased when increasing amounts of DDGS and HP-DDG were fed. These results indicate that pigs fed comparable dietary levels of HP-DDG to DDGS have similar ADG but pigs fed HP-DDG diets had greater gain efficiency. The greater carcass fat iodine value from pigs fed the HP-DDG diets was likely a result of the greater corn oil content in HP-DDG (10.27% ether extract) compared with conventional DDGS (8.03%).

Table 7. Comparison of growth performance, caloric efficiency, and carcass characteristics of growing-finishing pigs fed increasing dietary levels of conventional DDGS and HP-DDG (adapted from Rao et al., 2021)

		DDGS		HP-DDG	
Measure	**Control (0%)**	**15%**	**30%**	**15%**	**30%**
Initial body weight, kg	27.1	27.1	27.1	27.1	27.1
Final body weight, kg	130.0	127.3	127.8	129.0	128.0
Grower phase					
ADG, g	893	879	862	875	852
ADFI, g	1,870	1,840	1,828	1,825	1,721
G:F, g/kg	479	479	472	480	497
Caloric efficiency, kcal/kg	5,395	5,317	5,322	5,420	5,300
Finisher phase					
ADG, g	855	833	864	860	870
ADFI, g	2,609	2,604	2,644	2,555	2,510
G:F, g/kg	328	321	327	336	347
Caloric efficiency, kcal/kg	8,040	8,136	7,890	7,937	7,743
Overall					
ADG, g	876	857	865	870	863
ADFI, g	2,262	2,243	2,259	2,212	2,139
G:F, g/kg	388	382	384	394	404
Caloric efficiency, kcal/kg	6,747	6,758	6,655	6,699	6,586
Carcass characteristics					
Hot carcass weight, kg	94.9	92.5	92.1	94.0	92.0
Carcass yield, %	73.1	72.6	72.1	72.9	71.9
Backfat depth, mm	15.9	15.5	15.9	15.8	15.6
Loin depth, mm	67.0	67.0	66.9	67.3	66.7
Lean, %	57.2	57.5	57.2	57.3	57.4
Iodine value, g/100 g	64.8	69.0	73.7	72.9	80.0

Summary of HP-DDG Feeding Trials with Broilers

Fries-Craft and Bobeck (2019) determined the AME_n content, SID amino acid digestibility, and growth performance (42-d) of broilers fed diets containing of an unspecified source of HP-DDGS (34% CP). The AME_n content was determined to be 2,725 kcal/kg and SID of indispensable amino acids ranged from 81% (Lys) to 90% for arginine (Arg) and Leu. Feeding diets containing 15 and 20% HP-DDGS resulted in reduced body weight gain and feed conversion but had no effect on feed intake compared with feeding the 10% HP-DDGS diets (**Table 8**). Results from this study indicate that this source of HP-DDGS can be included up to 10% in broiler diets with no negative effects on growth performance and without requiring supplemental Lys and Arg in diets.

Table 8. Comparison of growth performance of Cobb 500 broilers fed diets containing 5% conventional DDGS and increasing concentrations of HP-DDGS for 42 days (adapted from Fries-Craft and Bobeck, 2019)

Measure	**5% DDGS**	**10% HP-DDGS**	**15% HP-DDGS**	**20% HP-DDGS**

Initial body weight, g	37.93	37.74	37.40	37.48
Starter (d 0 to 14)				
Day 14 body weight, kg	0.39^{a}	0.39^{a}	0.35^{b}	0.37^{a}
Body weight gain, kg	0.34^{a}	0.35^{a}	0.31^{b}	0.34^{a}
Feed intake, kg	0.51^{ab}	0.53^{a}	0.51^{b}	0.53^{a}
Feed:Gain	1.49^{c}	1.51^{c}	1.63^{a}	1.58^{b}
Grower (d 14 to 35)				
Day 35 body weight, kg	1.99^{ab}	2.02^{a}	1.91^{c}	1.93^{bc}
Body weight gain, kg	1.61^{ab}	1.64^{a}	1.56^{b}	1.55^{b}
Feed intake, kg	2.66^{ab}	2.74^{a}	2.63^{b}	2.70^{ab}
Feed:Gain	1.66^{c}	1.67^{bc}	1.69^{b}	1.76^{a}
Finisher (d 35 to 42)				
Day 42 body weight, kg	2.70^{a}	2.72^{a}	2.56^{b}	2.58^{b}
Body weight gain, kg	0.70^{a}	0.70^{ab}	0.65^{b}	0.65^{b}
Feed intake, kg	1.30^{a}	1.29^{ab}	1.24^{b}	1.26^{ab}
Feed:Gain	1.86	1.86	1.91	1.94
Overall (d 0 to 42)				
Body weight gain, kg	2.65^{a}	2.68^{a}	2.52^{b}	2.54^{b}
Feed intake, kg	4.47^{ab}	4.55^{a}	4.38^{b}	4.49^{ab}
Feed:Gain	1.69^{c}	1.70^{c}	1.74^{b}	1.77^{a}

[a,b,c] Means within rows with uncommon superscripts are difference ($P < 0.05$).

Hussain et al. (2019) evaluated diets containing 6.4% HP-DDGS (43% CP from an unspecified U.S. source) and the addition of protease, combination of mannanase and xylanase, and a combination of all three enzyme on growth performance, nutrient digestibility, and intestinal morphology of broilers. There were no effects of enzyme supplementation on body weight gain, feed intake, feed conversion, carcass characteristics, organ weight, intestinal morphology, nor energy and amino acid digestibility. These results indicate that the carbohydrases and protease evaluated in this study were not effective in improving growth performance, nutrient digestibility, and intestinal morphology of broilers.

Summary of HP-DDG Feeding Trials with Layers

Foley et al. (2022) evaluated the effects of feeding diets containing two new HP-DDG sources produced using ICM, Inc. fiber separation technology that contained 40.3% CP (FST1) and 39.1% CP (FST2) on feed intake, egg production, and AME content in White Leghorn laying hens from 21 to 45 weeks of age. Dietary treatments consisted of a corn-SBM control with no HP-DDG, and diets containing 5, 10, or 15% FST1 or FST2. Time × dietary treatment interactions were found for egg production, yolk color score, and eggshell breaking strength. Egg production improved during the later weeks of the trial in hens fed the 15% HP-DDG diets from either source. Yolk color score increased as HP-DDG level increased in the diet but decreased over time regardless of dietary treatment. Eggshell breaking strength was highest in hens fed the control and 15% FST2 diets, but HP-DDG source or level did not affect feed intake, egg weight, or hen body weight. The AME content of the 5% FST1 and 10% FST2 treatment groups and for all hens fed the HP-DDG diets compared to those fed the control diet. In summary, laying hens can be fed diets containing up to 15% HP-DDG produced using the ICM, Inc. fiber separation technology with no detrimental effects on feed intake or egg production with some improvements to yolk color and egg production in later stages of the laying cycle.

Summary of HP-DDG Feeding Trials with Aquaculture

Nile tilapia (*Oreochromis niloticus*)

Herath et al. (2016a) determined the effects of totally replacing fishmeal (21.8%) with CPC (19.4%), HP-DDG (33.2%), corn gluten meal (CGM; 23.5%), or DDGS (52.4%) in isonitrogenous diets on growth performance and body composition of juvenile (4.5 g initial average weight) Nile tilapia (*Oreochromis niloticus*) in a 12-week feeding trial. Fish fed the control diet containing 21.8% fishmeal and the 52.4% DDGS diet had the highest specific growth rate, feed intake, protein retention, and survival among all dietary treatments (**Table 9**). In contrast, fish fed the CGM and CPC diets had the lowest specific growth rate, thermal growth rate, feed intake, protein retention, and survival. Fish fed the HP-DDG diet had lower specific growth rate and thermal growth rate, but comparable feed intake and protein retention compared with those fed the control and DDGS diets. In addition, feeding the HP-DDG diet resulted in greater whole body and fillet protein content than fish the control and DDGS diets, along with greater lipid content compared to fish fed the control diet (**Table 9**). However, no differences were observed for any of the body indices measured. Results from this study indicate that completely replacing fishmeal with various corn co-products in juvenile Nile tilapia diets results in different effects on growth performance and whole body and fillet composition. Among the corn co-products evaluated, diets containing DDGS provided the best growth performance and composition responses but feeding the HP-DDG diet resulted in greater growth performance and whole body and fillet protein composition than feeding diets containing CGM and CPC without fishmeal.

Table 9. Comparison of growth performance, body indices, and fillet color of Nile tilapia (*Oreochromis niloticus*) fed corn co-product diets for 12 weeks (Adapted from Herath et al., 2016a)

Measure	Control	HP-DDG[1]	DDGS[2]	CGM[3]	CPC[4]
Growth performance					
Specific growth rate, %	3.56[a]	3.30[b]	3.53[a]	2.75[c]	2.63[d]
Thermal growth coefficient	1.21[a]	1.06[c]	1.16[b]	0.81[d]	0.76[e]
Feed intake, g dry weight	84.05[a]	71.05[a]	81.20[a]	40.2[b]	38.80[b]
Feed conversion ratio	1.00	1.05	1.05	1.00	1.10
Protein efficiency ratio	3.20	2.99	3.06	3.10	2.84
Protein retention, %	49.62[a]	46.17[ab]	46.70[ab]	42.02[bc]	38.42[c]
Survival, %	100.0[a]	80.6[bc]	97.2[ab]	66.6[c]	75.0[c]
Whole body composition, % wet basis					
Moisture	69.4	68.9	69.7	70.9	71.6
Protein	15.5[b]	16.7[a]	15.4[b]	14.6[c]	13.9[d]
Lipid	8.5[b]	9.9[a]	10.0[a]	9.8[a]	9.6[a]
Ash	6.9[a]	5.4[c]	5.7[b]	4.0[e]	5.0[d]
Fillet composition, % wet basis					
Moisture	78.2	76.2	77.2	77.9	78.5

Protein	18.8[b]	19.8[a]	18.3[b]	19.2[b]	18.7[b]
Lipid	1.6[c]	2.4[b]	3.1[a]	2.2[b]	1.9[bc]
Ash	1.4	1.2	1.3	1.3	1.4
Body indices					
Viscerosomatic index[5]	10.8	11.6	12.9	12.1	12.8
Hepatosomatic index[6]	3.0	2.1	2.7	2.2	2.0
Fillet yield[7], %	30.4	30.8	32.4	31.9	28.3
Coefficient of condition[8]	2.0	2.0	2.0	1.8	1.9

[a,b,c,d,e]Means with uncommon superscripts in each row are different ($P < 0.05$).
[1]HP-DDG = high protein distillers dried grains.
[2]DDGS = distillers dried grains with solubles.
[3]CGM = corn gluten meal.
[4]CPC = corn protein concentrate.
[5]Viscerosomatic index = 100 × visceral weight (g)/body weight (g).
[6]Hepatosomatic index = 100 × liver weight (g)/body weight (g).
[7]Fillet yield = 100 × fillet weight (g)/body weight (g).
[8]Coefficient of condition = 100 × body weight (g)/total length (cm^3).

In a subsequent longer term comparative study, Herath et al. (2016b) evaluated the effects of feeding corn co-product-based diets on growth performance, fillet color and composition of Nile tilapia (*Oreochromis niloticus*) during a 24-week feeding period. In this study, diets consisted of a control diet containing 10% FM (FM), and four other diets without fishmeal but containing HP-DDG (33.2%), DDGS (52.4%), CGM (23.5%), or CPC (19.4%) to replace 50% of the dietary protein. Fish (initial body weight = 21 g) fed the control, HP-DDG, and DDGS diets had greater mean weight gain, specific growth rate, mean feed intake, protein, efficiency ratio and improved feed conversion and survival than those fed CGM and CPC diets (**Table 10**). However, there was no effect of corn co-product on lightness, redness, yellowness, crude protein, and total amino acid content of fillets. Fish fed the CGM diet had the greatest lipid and ash content in fillets, while fillet fatty acid composition varied among dietary treatments. Results from this study indicate that adding HP-DDG or DDGS to non-fishmeal diets at levels up to 50% of dietary protein had no negative effects on growth performance or fillet color, but feeding diets containing CGM and CPC were detrimental to growth performance at these inclusion rates.

Table 10. Comparison of growth performance, body indices, fillet composition and color of Nile tilapia (*Oreochromis niloticus*) fed diets containing high-protein distillers dried grains (HP-DDG), distillers dried grains with solubles (DDGS), corn gluten meal (CGM), and corn protein concentrate (CPC) during a 24-week feeding period (adapted from Herath et al., 2016b)

Measure	Control	HP-DDG	DDGS	CGM	CPC
Growth performance					
Mean weight gain, g	162[a]	161[a]	161[a]	88[b]	75[b]
Specific growth rate, %	1.27[a]	1.26[a]	1.27[a]	0.96[b]	0.90[b]
Mean feed intake, g/fish	216[a]	222[a]	226[a]	149[b]	124[b]
Feed conversion ratio	1.33[b]	1.38[b]	1.40[b]	1.72[a]	1.66[a]
Protein efficiency ratio	2.31[a]	2.12[a]	2.30[a]	1.69[b]	1.68[b]
Survival, %	97.2[a]	97.2[a]	97.2[a]	91.7[a]	52.7[b]
Body indices					
Intraperitoneal fat ratio	1.88	2.22	1.50	2.02	1.34
Hepatosomatic index	2.70[b]	2.70[b]	1.93[c]	3.45[a]	2.30[bc]

Viscerosomatic index	9.33	10.92	9.44	11.62	11.50
Fillet yield	28.16	27.52	27.34	27.14	26.37
Condition factor	2.01^{a}	1.83^{c}	1.89^{bc}	1.94^{b}	1.87^{bc}
Fillet composition					
Moisture, %	77.85	77.60	77.35	77.30	77.70
Crude protein, %	19.60	19.60	19.65	19.40	19.35
Crude lipid, %	1.80^{b}	2.05^{ab}	2.20^{ab}	2.35^{a}	2.05^{ab}
Ash, %	1.30^{b}	1.30^{b}	1.26^{b}	1.60^{a}	1.50^{ab}
Tristimulus color of fillets					
L*	47.8	48.0	47.8	41.5	41.8
a*	1.3	0.7	1.2	1.8	2.3
b*	3.2	2.3	2.3	1.3	2.2
Chroma[1]	3.5	2.4	2.7	1.9	3.3
Hue angle[2], degrees	67.5	74.0	54.5	53.6	43.3
ΔE[3]	0	1.11	0.97	6.61	6.22

[a.b.c] Means within rows with uncommon superscripts are different ($P < 0.05$)
[1]Chroma = intensity of color.
[2]Hue angle = 0° for redness and 90° for yellowness.
[3]ΔE = total color difference compared with control.

Striped catfish (*Pangasianodon hypophthalmus*)

A HP-DDG co-product containing 40% CP, 3.1% ether extract, 28.1% crude fiber, and 2.4% ash was added to isonitrogenous, isolipidic, and isocaloric diets for striped catfish (*Pangasianodon hypophthalmus*) at increasing levels (0, 5.8, 11.6, and 17.4%) to partially replace FM to evaluate growth performance and economic benefits (Allam et al., 2020). Replacing 25% of FM with HP-DDG (5.8% of total diet) resulted in acceptable growth rate and feed conversion but replacing greater amounts of FM linearly decreased growth and feed conversion. Furthermore, whole-body protein content was reduced, and lipid content was increased at the highest dietary HP-DDG inclusion rate. The negative effects of HP-DDG added at 11.6 and 17.4% on growth performance and body composition was likely due to inadequate Lys, Met, and other essential amino acids which can be corrected with the addition of adequate amounts of supplemental crystalline amino acids.

Channel catfish (*Ictalurus punctatus*)

Tidwell et al. (2017) evaluated a HP-DDG co-product to determine effects of increasing dietary levels (0, 20, 40, and 40% + crystalline lysine) on pellet characteristics and growth performance of juvenile channel catfish (*Ictalurus punctatus*). Average harvest weight of fish fed the 20% HP-DDG diet was greater (86.8 g) than those fed the 40% HP-DDG (57.0 g) and 40% HP-DDG + supplemental lysine (73.7 g), but there were no differences in feed conversion or survival among dietary treatments. Whole-body protein concentration was greater in fish fed the control diet compared with those fed the 40% HP-DDG with and without supplemental lysine, but moisture, lipid, and ash content were not affected. Increasing dietary HP-DDG levels resulted in decreased pellet expansion ratio, tended to increase unit density and pellet durability index. These results indicate that supplemental Lys, and perhaps other essential amino acids in HP-DDG diets is necessary at diet inclusion rates greater than 20% to support optimal growth performance and fillet composition. However, producing pellets with high pellet durability index can be achieved at high dietary inclusion rates of HP-DDG.

A recent study compared the effect of adding increasing dietary levels of HP-DDG (ANDVantage™ 40Y) to partially replace poultry meal or SBM in diets for juvenile channel catfish (Nazeer et al., 2022). Isonitrogenous (32% CP) and isolipidic (6.5% lipid) diets were formulated to contain 0, 3.1, 6.2, and 9.3% HP-DDG to replace 6, 4, 2, and 0% poultry meal, respectively, and 5, 10, 15, 20, 30, and 40% HP-DDG to replace 51, 46.5, 41.9, 37.4, 28.2, and 19.2% SBM, respectively. All diets were pelleted and fed to juvenile channel catfish (*Ictalurus punctatus*; average initial weight of 1.8 g) in the first trial. A second trial was conducted to confirm the low feed intake responses of fish fed the 9.3% HP-DDG diet replacing poultry meal at two feeding rates. There was a significant interaction between dietary inclusion level of HP-DDG and protein source replaced (poultry meal or SBM). When increasing levels of HP-DDG replaced increasing amounts of poultry meal in the diets, growth, feed intake, feed conversion, and net protein retention were reduced, especially when feeding the 9.3% HP-DDG diet (**Table 11**). However, there were no differences among dietary HP-DDG levels on survival, and whole-body moisture, crude protein, crude lipid, and ash content (**Table 11**). However, when increasing HP-DDG levels were added to replace portions of SBM in diets, there were no differences in growth performance among dietary treatments except for the 30 and 40% HP-DDG diets (**Table 12**). Again, fish survival and whole-body moisture, crude protein, crude lipid, and ash content was not affected by dietary HP-DDG inclusion rate (**Table 12**). Results from this study indicate that HP-DDG is a good protein source for channel catfish diets but should be limited to no more than 20% of the diet when partially replacing SBM to avoid reductions in growth performance. However, when HP-DDG (9.3%) was used to completely replace poultry meal, poor growth performance resulted which was likely due to a nutritional deficiency.

Table 11. Comparison of growth performance and whole-body composition of channel catfish fed diets containing increasing amounts of high-protein distillers dried grains (HP-DDG; (ANDVantage™ 40Y) to partially replace poultry meal during a 10-week feeding period (adapted from Nazeer et al., 2022)

Measure	Control	3.1% HP-DDG	6.2% HP-DDG	9.3% HP-DDG
Growth performance				
Final biomass, g	479[a]	445[ab]	411[b]	351[c]
Final weight, g/fish	24.26[a]	22.25[ab]	21.40[b]	18.02[c]
Weight gain, g/fish	22.41[a]	20.50[ab]	19.62[b]	16.18[c]
Weight gain, %	1,215[a]	1,169[a]	1,103[a]	882[b]
Total dry feed, g/fish	24.35[a]	23.27[a]	23.52[a]	20.50[b]
Feed conversion ratio	1.09[c]	1.14[bc]	1.20[ab]	1.27[a]
Survival, %	98.75	100.0	96.25	97.50
Net protein retention, %	42.85[a]	40.43[ab]	38.47[ab]	33.90[b]
Whole body composition, %				
Moisture	72.15	72.15	73.12	75.13
Crude protein	14.65	14.40	14.40	13.80
Crude lipid	8.98	9.16	8.42	7.78
Ash	2.64	3.17	2.89	2.49

[a.b.c] Means within rows with uncommon superscripts are different ($P < 0.05$)

Table 12. Comparison of growth performance and whole-body composition of channel catfish fed diets containing increasing amounts of high-protein distillers dried grains (HP-DDG; (ANDVantage™ 40Y) to partially replace SBM during a 10-week feeding period (adapted from Nazeer et al., 2022)

Measure	Dietary HP-DDG inclusion rate, %						
	0	**5**	**10**	**15**	**20**	**30**	**40**
Growth performance							
Final biomass, g	479[a]	493[a]	504[a]	512[a]	507[a]	403[b]	253[c]
Final weight, g/fish	24.26[a]	24.64[a]	25.18[a]	25.92[a]	26.00[a]	20.15[b]	12.65[c]
Weight gain, g/fish	22.41[a]	22.85[a]	23.33[a]	24.13[a]	24.19[a]	18.35[b]	10.88[c]
Weight gain, %	1,215[a]	1,277[a]	1,263[a]	1,349[a]	1,340[a]	1,020[b]	613[c]
Total dry feed, g/fish	24.35[a]	24.24[bc]	24.83[ab]	25.30[ab]	25.65[a]	23.32[c]	18.30[d]
Feed conversion ratio	1.09[c]	1.06[c]	1.07[c]	1.05[c]	1.06[c]	1.27[b]	1.68[a]
Survival, %	98.75	100.0	100.0	98.75	100.0	100.0	100.0
Net protein retention, %	42.85[a]	42.11[ab]	44.82[a]	43.78[a]	43.65[a]	35.26[b]	24.39[c]
Whole body composition, %							
Moisture	72.15	72.47	70.72	71.65	71.55	73.37	73.40
Crude protein	14.65	13.57	15.02	14.05	13.92	13.90	13.15
Crude lipid	8.98	9.31	9.50	9.52	9.86	8.78	8.23
Ash	2.64	3.15	3.19	3.31	2.82	2.96	3.21

[a.b.c,d] Means within rows with uncommon superscripts are different (P < 0.05)

Yellow perch (*Perca flavescens*)

Von Eschen et al. (2021) evaluated a source of HP-DDG containing 40% CP as a partial or complete replacement for herring fishmeal (72% CP) in juvenile yellow perch (*Perca flavescens*) diets in a 105-day feeding trial. Experimental diets contained increasing replacement levels of 25, 50, 75, and 100% of FM with HP-DDG. Weight gain, feed conversion, apparent protein digestibility, and condition factor were negatively correlated with increasing dietary levels of HP-DDG. As the fishmeal inclusion rate decreased in diets, growth performance also decreased, but survival was 100% across all treatments. Results from this study indicate that the addition of HP-DDG to yellow perch diets should not exceed a 50% replacement rate, and supplemental synthetic lysine may improve growth performance.

Summary of HP-DDG Feeding Trials with Lactating Dairy Cows

An unpublished study conducted by Zynda et al. (2021) evaluated feeding diets containing HP-DDG (ICM, Inc.) at 20% of dry matter intake, with and without yeast or manipulation of dietary cation and anion difference (DCAD) on milk production, nutrient digestibility, and gas emissions from manure in lactating dairy cows. Compared with feeding the control SBM-based diet, feeding HP-DDG reduced milk yield as a result of decreased organic matter and NDF digestibility, and reduced milk fat yield as a result of high polyunsaturated fatty acid content and low DCAD. However, elevating DCAD in HP-DDG diets by supplementing cations was effective in alleviating milk fat depression, but there were no beneficial effects of HP-DDG with yeast for any measures evaluated. Furthermore, because of the relatively high concentration of phosphorus and sulfur in

HP-DDG, phosphorus and sulfur excretion were increased in manure of cows fed HP-DDG which also increased hydrogen sulfide emissions. These results emphasize the importance of balancing DCAD when feeding high amounts of HP-DDG to lactating dairy cows to avoid milk fat depression but feeding HP-DDG with greater yeast content did not provide improvements in milk production, milk composition, nutrient digestibility, or reduce gas emissions from manure.

Conclusions

The sources of HP-DDG available in the market have a substantially different nutritional profile than HP-DDG sources produced and evaluated 10 to 15 years ago, and also varies significantly among current sources. Therefore, it is essential to communicate with your HP-DDG supplier to obtain the actual energy, digestible amino acids, and digestible phosphorus data specific to HP-DDG source being fed to ensure accurate diet formulation and achieve optimal animal performance. Theoretically, the addition of appropriate carbohydrases and proteases to swine, poultry, and aquaculture diets may improve the utilization of dietary fiber and ME content in HP-DDG diets, but limited studies thus far for swine and poultry indicate that this is not an effective strategy. Although HP-DDG has greater CP and digestible amino acid content than conventional DDGS, it contains excess Leu relative to Ile and Val which reduces feed intake and growth rate in swine nursery and growing-finishing diets containing increasing levels of HP-DDG. Therefore, dietary supplementation of several crystalline amino acids (e.g., Lys, Thr, Trp, Ile, Val) may be needed to overcome reduced feed intake and growth depending on the diet inclusion rate of HP-DDG used. Limited studies in broilers and layers indicate that HP-DDG can support satisfactory performance when HP-DDG is limited to 10% of the diet for broilers and 15% for layers. In general, it appears that HP-DDG can be used to replace up to 50% of dietary protein in non-fishmeal diets for Nile tilapia and yellow perch, but supplemental lysine may be necessary to support optimal growth performance. For striped catfish and channel catfish, no more than 20% HP-DDG as a partial replacement for SBM is recommended, and supplementation of Lys and other indispensable amino acids may be necessary to support optimal growth performance. The use of HP-DDG in lactating dairy cow diets can support satisfactory milk production and composition but diet formulation adjustments to balance the dietary cation and anion difference is an important consideration for optimizing its use.

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