Evaluating the Productive Energy Content of High-Protein Distillers Dried Grains in Swine Diets[1]

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Summary

A total of 300 pigs (DNA 400 × 200), initially 24.5 lb, were used in a study to evaluate the effects of increasing amounts of high-protein distillers dried grains (HP DDG) on growth performance, and to estimate the productive energy of HP DDG. Pens were allocated with 5 pigs each and fed a common diet for 21 d after weaning. Then, pens were assigned to treatments in a randomized complete block design. There were 5 treatments with 12 pen replicates per treatment. Treatments consisted of 0, 10, 20, 30, or 40% HP DDG. Pigs were weighed weekly for 21 d to evaluate average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (F/G). Caloric efficiency was obtained by multiplying ADFI by kcal of net energy (NE) per lb of diet and dividing by ADG. Productive energy was estimated based on caloric efficiency relative to the diet without HP DDG. Data were analyzed with the GLIMMIX procedure of SAS with block as a random effect and pen as the experimental unit. From d 0 to 7 and 7 to 14, increasing amounts of HP DDG linearly decreased ($P < 0.01$) ADG, which was mainly driven by lower (linear, $P < 0.01$) ADFI. The inclusion of HP DDG negatively impacted (linear; $P < 0.01$) F/G from d 0 to 7 with no evidence for differences from d 7 to 14 ($P \geq 0.321$). From d 14 to 21, there was a decrease (linear, $P < 0.01$) in ADFI and improvement (linear, $P = 0.029$) in F/G as HP DDG inclusion increased. Overall (d 0 to 21), pigs fed diets with increasing HP DDG had a linear decrease ($P < 0.01$) in ADG, ADFI, and final body weight. There was a tendency for a quadratic response ($P = 0.051$) in F/G, with the best F/G observed for pigs fed diets with 40% HP DDG. There was a linear reduction ($P < 0.01$) in caloric efficiency with increasing amounts of HP DDG, indicating an underestimation of HP DDG NE. The productive energy of HP DDG was estimated as 1,218 kcal/lb or 97.3% of corn NE.

Introduction

Distillers dried grains with solubles is a co-product of the ethanol industry that is widely used in swine diets. New processing techniques are being developed to remove nonfer-

[1] The authors thank ICM (Colwich, KS) for technical and partial financial support and providing the high-protein dried distillers grains.

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mentable components before fermentation[4] that result in HP DDG with approximately 40% crude protein (CP). The new product generated has a different chemical composition and nutritive value for swine diets. Therefore, it is critical to characterize the nutrient profile of HP DDG and its effects on growth performance. Recently, Rho et al.[5] determined the standardized ileal digestibility of amino acids (AA) and digestible energy (DE) content of HP DDG and observed similar AA digestibility but approximately 25% greater DE than conventional DDG. However, growth performance was not evaluated in that study and it was not clear if the higher DE content would translate to improved growth performance. Productive energy values are determined by feeding increasing levels of an ingredient and using the difference in F/G to calculate the energy content of the test ingredient relative to a known ingredient, e.g. corn.[6] This method is less time-consuming than determining NE using direct or indirect calorimetry and can be used to more closely predict growth performance. Therefore, the objective of this study was to determine the growth performance of pigs fed increasing amounts of HP DDG and to evaluate its productive energy content.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan, KS. A total of 300 pigs (DNA 400 × 200; initially 24.5 lb) were used in a 21-d growth trial with 5 pigs per pen and 12 replicates per treatment. At arrival at the research facility, pigs were randomly placed in pens and fed common diets for 21 d until they reached approximately 25 lb. Pens had tri-bar floors and allowed approximately 2.7 ft^2 per pig. Each pen contained a 4-hole, dry self-feeder, and a cup waterer to provide *ad libitum* access to feed and water.

On d 21 after arrival, which was considered d 0 of the experiment, pens of pigs were blocked by weight and randomly assigned to 1 of 5 dietary treatments. Treatments consisted of corn-soybean meal diets with increasing levels of HP DDG at 0, 10, 20, 30, or 40% of the diet. The inclusion of HP DDG was done at the expense of corn and feed-grade amino acids while soybean meal inclusion was held constant (Table 4). Feed-grade amino acids were assigned NE values of 1,529, 1,876, 1,334, 2,168, 1,962, and 2,162 kcal/lb for L-lysine HCl, DL-methionine, L-threonine, L-tryptophan, L-valine, and L-isoleucine, respectively. Diets were not balanced for NE. Experimental diets were fed for 21 d. Pigs were weighed and feed disappearance was measured on d 0, 7, 14, and 21 to determine ADG, ADFI, and F/G.

Caloric efficiency was obtained by multiplying ADFI by kcal of NE per lb of diet and dividing by ADG. Corn and soybean meal were assigned NE values obtained from the

[4] Sekhon, J. K., S. Jung, T. Wang, K. A. Rosentrater, and L. A. Johnson. 2015. Effect of co-products of enzyme-assisted aqueous extraction of soybeans on ethanol production in dry-grind corn fermentation. Bioresour. Technol. 192:451-460.

[5] Rho, Y., C. Zhu, E., Kiarie, and C.F.M. De Lange. 2017 Standardized ileal digestible amino acids and digestible energy contents in high-protein distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 95:3591-3597.

[6] Boyd, R. D., C. E. Zier-Rush, and C. E. Fralick. 2010. Practical method for estimating productive energy (NE) of wheat midds for growing pigs. J. Anim. Sci. 88(E-Suppl. 3):153 (Abstr.).

NRC.[7] The NE value for HP DDG was estimated utilizing three different methods: 1) The equation from Noblet and Perez[8] was used to estimate DE and that DE value was used in the Noblet et al.[9] equation for NE; 2) DE estimates from equations of Anderson et al.[10] were used in the Noblet et al.[9] equation for NE; or 3) DE values determined by Rho et al.[5] were used in Noblet et al.[9] equation for NE. Based on the caloric efficiency, a predicted NE value for each treatment that contained HP DDG compared to the corn-soybean meal diet was calculated and average productive energy was estimated.

Diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center in Manhattan, KS. Representative diet samples were obtained from each treatment and analyzed for dry matter, CP, Ca, P, and neutral detergent fiber (Ward Laboratories, Inc., Kearney, NE). Corn, soybean meal, and HP DDG samples were analyzed for total amino acids (Agricultural Experiment Station Chemical Laboratories, University of Missouri-Columbia, MO) and these values were used for diet formulation. Samples of HP DDG were also analyzed for gross energy (Kansas State University Analytical Laboratory, Manhattan, KS), dry matter, CP, acid detergent fiber, neutral detergent fiber, ether extract, starch, and ash (Ward Laboratories, Inc., Kearney, NE) to estimate NE and mycotoxins content (North Dakota State University Veterinary Diagnostic Laboratory, Fargo, ND).

Data were analyzed as a randomized complete block design with block as a random effect and pen as the experimental unit. Polynomial contrasts were constructed to evaluate the linear and quadratic effects of increasing HP DDG. Data were analyzed using the GLIMMIX procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$ and a tendency at $0.05 < P \leq 0.10$.

Results and Discussion

Total amino acid analysis and proximate analysis of individual ingredients are presented in Tables 1 and 2. The total amino acid content of HP DDG was similar to that observed by Rho et al.[5] Mycotoxins were less than the detectable values except for deoxynivalenol, which was present at 560 ppb (Table 3). Levels of deoxynivalenol less than 1,000 ppb are not thought to impact pig performance. The proximate analysis of diets was consistent with formulated estimates (Table 5).

From d 0 to 7 and 7 to 14, there was a decrease (linear; $P < 0.01$) in ADG with increasing HP DDG (Table 6). The response in ADG was mainly driven by lower (linear; $P < 0.01$) ADFI observed from d 0 to 7 and 7 to 14. The inclusion of HP DDG negatively impacted (linear; $P < 0.01$) F/G from d 0 to 7 with no evidence for differ-

[7] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

[8] Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389-3398.

[9] Noblet, J., H. Fortune, X.S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344-354.

[10] Anderson, P.V., B.J. Kerr, T.E. Weber, C.J. Ziemer, and G.C. Shurson. 2012. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn coproducts fed to finishing pigs. J. Anim. Sci. 90:1242-1254.

ences ($P \geq 0.321$) from d 7 to 14. Although ADFI also decreased (linear; $P < 0.01$) from d 14 to 21, there was no evidence for differences ($P \geq 0.162$) in ADG in this period.

These results indicate that the initial exposure to HP DDG in the diet elicited a negative response in performance, but these effects were no longer observed after two weeks. Interestingly, pigs fed diets with increasing levels of HP DDG presented an improvement (linear; $P = 0.029$) in F/G from d 14 to 21, which could indicate a compensatory response.

Overall (d 0 to 21), pigs fed diets with increasing HP DDG had a linear decrease ($P < 0.01$) in ADG, ADFI, and final weight. There was a tendency for a quadratic response ($P = 0.051$) in F/G, with the best F/G observed for pigs fed the diet with 40% HP DDG.

Using the DE value estimated by Noblet and Perez[8] in the Noblet et al.[9] equations resulted in a NE estimate of 868 kcal/lb for HP DDG. The DE equations of Anderson et al.[10] coupled with the Noblet et al.[9] equations resulted in a slightly higher estimate of 984 kcal/lb NE. Finally, using DE energy values from the Rho et al.[5] in the Noblet et al.[9] equation resulted in the highest NE estimate of 1142 kcal/lb. The estimated NE for corn and soybean meal were similar to those presented in the NRC,[7] thus the NRC values were used to estimate productive energy of HP DDG.

All equations resulted in similar responses in caloric efficiency, except from d 0 to 7 where combining the Noblet and Perez[8] and Noblet et al.[9] equations resulted in a linear decrease ($P < 0.05$) in caloric efficiency, while no evidence for difference ($P > 0.10$) was observed using combinations of the Anderson et al.[10] and Noblet et al.[9] or Rho et al.[5] and Noblet et al.[9] equations.

Overall, there was a decrease (linear; $P < 0.01$) in caloric efficiency as HP DDG increased, which indicates that the NE of HP DDG was underestimated. Results suggest that in order to obtain a caloric efficiency similar to the corn-soybean meal diet, the NE value of HP DDG should be 1,218 kcal/lb or 97.3% of corn NE. In comparison, the initial NE value was 69.2% of corn NE using the Noblet and Perez[8] and Noblet et al.[9] equations, 78.6% of corn NE using the Anderson et al.[10] and Noblet et al.[9] equations, and 91.2% of corn NE using the Rho et al.[5] DE values and Noblet et al.[9] equation.

In summary, our results suggest that pigs initially respond negatively to the inclusion of HP DDG, but this response is lessened as pigs adapt to the ingredient. The equations used to estimate NE of HP DDG resulted in underestimated values. The best estimate was produced using the Rho et al.[5] DE values and Noblet et al.[9] equation for NE. Based on caloric efficiency, the productive energy of HP DDG is approximately 97% of corn NE.

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Table 1. Chemical analysis of corn, soybean meal, and high-protein distillers dried grains (HP DDG) (as-fed basis)[1]

Proximate analysis, %	Corn	Soybean meal	HP DDG
Dry matter	87.1	89.8	91.4
Crude protein	7.4	47.3	39.0
Ether extract	2.7	1.3	8.4
Ash	1.2	5.9	3.1
Neutral detergent fiber	5.8	11.1	36.0
Acid detergent fiber	1.8	9.5	21.3
Starch	59.0	1.2	2.3

[1]A representative sample of each ingredient was collected, homogenized, and submitted to Ward Laboratories, Inc., (Kearney, NE) for proximate analysis in duplicate.

Table 2. Amino acid analysis of corn, soybean meal, and high-protein distillers dried grains (HP DDG) (as-fed basis)[1]

Amino acid, %	Corn	Soybean meal	HP DDG
Alanine	0.56	2.01	2.79
Arginine	0.37	3.38	1.64
Aspartic acid	0.53	5.27	2.52
Cysteine	0.19	0.70	0.83
Glutamic acid	1.39	8.48	6.26
Glycine	0.31	2.00	1.54
Histidine	0.22	1.20	1.06
Isoleucine	0.28	2.27	1.67
Leucine	0.88	3.58	4.93
Lysine	0.27	3.01	1.22
Methionine	0.18	0.66	0.83
Phenylalanine	0.38	2.38	2.08
Proline	0.67	2.37	3.21
Serine	0.34	2.01	1.63
Threonine	0.28	1.81	1.47
Tryptophan	0.06	0.63	0.32
Tyrosine	0.23	1.72	1.56
Valine	0.38	2.32	2.05

[1]A representative sample of each ingredient was collected, homogenized, and submitted to Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, MO) and analyzed in duplicate.

Table 3. Mycotoxins analysis of high-protein distillers dried grains (HP DDG)[1]

Mycotoxins, ppb	PQL,[2] ppb	HP DDG
Aflatoxin B1	20	< 20
Aflatoxin B2	20	< 20
Aflatoxin G1	20	< 20
Aflatoxin G2	20	< 20
Deoxynivalenol	200	560
Fumonisin B1	200	< 200
Fumonisin B2	200	< 200
HT-2 toxin	200	< 200
Ochratoxin A	20	< 20
T-2 toxin	20	< 20
Sterigmatocystin	20	< 20
Zearalenone	100	< 100

[1]A representative sample of HP DDG was collected, homogenized, and submitted to North Dakota State University Veterinary Diagnostic Lab (Fargo, ND). Mycotoxins were extracted in acetonitrile and water followed by chromatography/mass spectrometry/mass spectrometry (LC/MS/MS) detection.
[2]PQL = practical quantitation limit.

Table 4. Diet composition (as-fed basis)[1]

	HP DDG[2] inclusion, %				
Ingredients, %	0	10	20	30	40
Corn	68.6	59.3	49.7	40.0	30.3
Soybean meal, 47% crude protein	26.5	26.5	26.5	26.5	26.5
HP DDG	---	10.0	20.0	30.0	40.0
Calcium carbonate	0.98	1.05	1.13	1.18	1.25
Monocalcium phosphate, 21.5% P	1.60	1.35	1.15	0.95	0.75
Sodium chloride	0.50	0.50	0.50	0.50	0.50
L-Lysine HCl	0.58	0.51	0.45	0.39	0.33
DL-Methionine	0.22	0.12	0.01	---	---
L-Threonine	0.30	0.21	0.13	0.06	---
L-Tryptophan	0.06	0.05	0.03	0.01	---
L-Valine	0.17	0.04	---	---	---
L-Isoleucine	0.10	---		---	---
L-Histidine	0.06	---	---	---	---
Vitamin-trace mineral premix	0.40	0.40	0.40	0.40	0.40
Total	100.0	100.0	100.0	100.0	100.0

continued

Table 4. Diet composition (as-fed basis)[1]

	HP DDG[2] inclusion, %				
Ingredients, %	0	10	20	30	40
Standardized ileal digestible (SID) amino acids, %					
Lysine	1.30	1.30	1.30	1.30	1.30
Isoleucine:lysine	61	61	69	77	85
Leucine:lysine	105	131	157	184	210
Methionine:lysine	37	33	29	33	37
Methionine and cystine:lysine	57	57	57	64	72
Threonine:lysine	65	65	65	65	67
Tryptophan:lysine	19.0	19.0	19.0	19.0	19.8
Valine:lysine	70	70	77	86	96
Histidine:lysine	36	36	41	45	50
Net energy,[3] kcal/lb	1,133	1,095	1,057	1,020	982
Crude protein, %	19.5	22.2	25.1	28.1	31.0
Neutral detergent fiber, %	8.4	11.2	13.9	16.6	19.3
Calcium, %	0.82	0.82	0.82	0.82	0.82
STTD P,[4] %	0.45	0.45	0.45	0.45	0.45

[1]Experimental diets were fed for 21 d.
[2]HP DDG = high-protein distillers dried grains.
[3]Initial net energy estimates were obtained using NRC* values for corn and soybean meal. For HP DDG, digestible energy value was first derived using the Noblet and Perez et al.** equation: DE = 4,168 – (9.1 × ash) + (1.9 × crude protein) + (3.9 × ether extract) – (3.6 × NDF), and net energy value was then derived from the Noblet et al.*** equation: NE = (0.700 × digestible energy) + (1.61 × ether extract) + (0.48 × starch) – (0.91 × crude protein) – (0.87 × acid detergent fiber), using analyzed values for ether extract, starch, crude protein, acid detergent fiber, and neutral detergent fiber.
[4]STTD P = standardized total tract digestible phosphorus.
*National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.
**Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389-3398.
***Noblet, J., H. Fortune, X.S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344-354.

Table 5. Chemical analysis of diets (as-fed basis)[1]

	HP DDG[2] inclusion, %				
Proximate analysis, %	0	10	20	30	40
Dry matter	89.0	89.4	89.8	90.0	90.3
Crude protein	19.0	21.7	24.4	27.2	30.1
Neutral detergent fiber	5.2	7.2	10.5	15.4	17.4
Calcium	1.07	0.85	0.93	0.96	0.94
Phosphorus	0.65	0.56	0.57	0.57	0.57

[1]A representative sample of each diet was collected from each treatment, homogenized, and submitted to Ward Laboratories, Inc. (Kearney, NE) for proximate analysis in duplicate.
[2]HP DDG = high-protein distillers dried grains.

Table 6. Effects of high-protein distillers dried grains (HP DDG) on nursery pig performance[1,2]

	HP DDG, %						Probability, *P* <	
Item[3]	0	10	20	30	40	SEM	Linear	Quadratic
BW, lb								
d 0	24.5	24.4	24.4	24.4	24.5	0.398	0.985	0.814
d 7	31.5	31.1	30.7	29.9	30.1	0.617	0.001	0.517
d 14	39.8	40.1	38.4	37.4	38.0	0.797	0.001	0.361
d 21	49.3	49.9	47.3	46.7	47.1	0.866	0.001	0.366
d 0 to 7								
ADG, lb	1.01	0.96	0.90	0.78	0.81	0.042	0.001	0.518
ADFI, lb	1.48	1.45	1.37	1.26	1.26	0.047	0.001	0.826
F/G	1.49	1.54	1.52	1.64	1.57	0.041	0.049	0.463
CE,[4] kcal/lb gain (Noblet*)	1,688	1,682	1,610	1,677	1,538	43.3	0.032	0.440
CE,[5] kcal/lb gain (Anderson**)	1,688	1,700	1,645	1,733	1,612	44.3	0.403	0.459
CE,[6] kcal/lb gain (Rho***)	1,688	1,723	1,694	1,812	1,711	45.6	0.354	0.466
d 7 to 14								
ADG, lb	1.18	1.28	1.09	1.07	1.13	0.041	0.006	0.522
ADFI, lb	1.82	1.88	1.68	1.63	1.64	0.045	0.001	0.668
F/G	1.55	1.47	1.54	1.53	1.47	0.033	0.321	0.684
CE, kcal/lb gain (Noblet)	1,755	1,613	1,632	1,558	1,444	34.8	0.001	0.772
CE, kcal/lb gain (Anderson)	1,755	1,630	1,668	1,610	1,513	35.6	0.001	0.763
CE, kcal/lb gain (Rho)	1,755	1,653	1,717	1,684	1,605	36.8	0.023	0.720
d 14 to 21								
ADG, lb	1.35	1.40	1.27	1.34	1.31	0.034	0.162	0.760
ADFI, lb	2.19	2.32	2.10	2.11	2.03	0.049	0.001	0.256
F/G	1.62	1.66	1.66	1.58	1.56	0.031	0.029	0.071
CE, kcal/lb gain (Noblet)	1,835	1,814	1,753	1,610	1,533	32.3	0.001	0.075
CE, kcal/lb gain (Anderson)	1,835	1,834	1,791	1,664	1,606	33.2	0.001	0.079
CE, kcal/lb gain (Rho)	1,835	1,859	1,844	1,740	1,704	34.4	0.001	0.075

continued

Table 6. Effects of high-protein distillers dried grains (HP DDG) on nursery pig performance[1,2]

	HP DDG, %						Probability, *P* <	
Item[3]	0	10	20	30	40	SEM	Linear	Quadratic
d 0 to 21								
ADG, lb	1.18	1.21	1.09	1.06	1.08	0.027	0.001	0.385
ADFI, lb	1.83	1.89	1.71	1.66	1.64	0.040	0.001	0.715
F/G	1.55	1.55	1.58	1.57	1.52	0.017	0.405	0.051
CE, kcal/lb gain (Noblet)	1,758	1,702	1,668	1,597	1,496	17.7	0.001	0.066
CE, kcal/lb gain (Anderson)	1,758	1,721	1,705	1,650	1,568	18.1	0.001	0.064
CE, kcal/lb gain (Rho)	1,758	1,744	1,755	1,725	1,664	18.7	0.001	0.058

[1]A total of 300 pigs were used in a 21-d study with 5 pigs per pen and 12 replicates per treatment.
[2]Diets contained 1,133, 1,095, 1,057, 1,020, and 982 kcal/lb calculated net energy, respectively. Net energy values for corn and soybean meal were obtained from NRC (National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298).
[3]BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed efficiency. CE = caloric efficiency.
[4]For CE (Noblet*), digestible energy value for HP DDG was first derived using the Noblet and Perez et al.* equation: DE = 4,168 – (9.1 × ash) + (1.9 × crude protein) + (3.9 × ether extract) – (3.6 × NDF), and net energy value was then derived from the Noblet et al.**** equation: NE = (0.700 × digestible energy) + (1.61 × ether extract) + (0.48 × starch) – (0.91 × crude protein) – (0.87 × acid detergent fiber), using analyzed values for ether extract, starch, crude protein, acid detergent fiber, and neutral detergent fiber.
[5]For CE (Anderson et al.**), digestible energy value for HP DDG was first derived using values were obtained using the Anderson et al.** equation: –2,161 + (1.39 × gross energy) – (20.7 × neutral detergent fiber) – (49.3 × ether extract), and net energy value was then derived from the Noblet et al.**** equation: NE = (0.700 × digestible energy) + (1.61 × ether extract) + (0.48 × starch) – (0.91 × crude protein) – (0.87 × acid detergent fiber), using analyzed values for gross energy, ether extract, starch, crude protein, acid detergent fiber, and neutral detergent fiber.
[6]For CE (Rho***), digestible energy value for HP DDG was first obtained from the Rho et al.***, and net energy value was then derived from the Noblet et al.**** equation: NE = (0.700 × digestible energy) + (1.61 × ether extract) + (0.48 × starch) – (0.91 × crude protein) – (0.87 × acid detergent fiber), using analyzed values for ether extract, starch, crude protein, and acid detergent fiber.
*Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389-3398.
**Anderson, P.V., B.J. Kerr, T.E. Weber, C.J. Ziemer, and G.C. Shurson. 2012. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn coproducts fed to finishing pigs. J. Anim. Sci. 90:1242-1254.
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****Noblet, J., H. Fortune, X.S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344-354.