Effects of distillers dried grains with solubles on amino acid digestibility, growth performance, and carcass characteristics of growing pigs[1]

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ABSTRACT: Two experiments were conducted to compare the standardized ileal digestibility (SID) of AA by growing pigs in European distillers dried grains with solubles (DDGS) produced from wheat, maize, or wheat–maize mixtures and to test the effect of increasing the inclusion levels of wheat DDGS on growth performance of growing-finishing pigs fed diets balanced for NE and SID Lys. In Exp. 1, 12 barrows (initial BW: 23.0 ± 2.2 kg) were surgically equipped with a T-cannula in the distal ileum and randomly allotted to a replicated 6 × 6 Latin square design with six diets and six periods. Five sources of European DDGS were used: wheat DDGS from 2011, wheat DDGS from 2012, wheat-80 DDGS (80% wheat and 20% maize), wheat-70 DDGS (70% wheat and 30% maize), and maize DDGS. Each diet contained one source of DDGS as the sole source of AA and an N-free diet was used to determine basal endogenous losses of AA. Results indicated that the SID of CP was greater ($P < 0.05$) in maize DDGS compared with wheat DDGS from 2011, wheat DDGS from 2012, and wheat-70 DDGS. The SID of all indispensable AA except Trp was also greater ($P < 0.05$) in maize DDGS compared with all other DDGS sources used in this experiment. For Trp, the SID in wheat-80 DDGS, wheat DDGS from 2011, and wheat DDGS from 2012 were not different from maize DDGS, but were greater ($P < 0.05$) than in wheat-70 DDGS. The SID for all indispensable AA except Ile and Trp in wheat-70 DDGS were not different from the values calculated for wheat DDGS from 2011 and wheat DDGS from 2012, and no differences between SID values for AA in wheat DDGS from 2011 and wheat DDGS from 2012 were observed. In Exp. 2, 36 growing pigs (initial BW: 38.3 ± 1.97 kg) were randomly allotted to one of four dietary treatments (one pig/pen and nine replicate pigs/treatment) in a 2-phase feeding program (35 to 65, and 35 to 105 kg BW). The four dietary treatments included diets containing 0%, 10%, 20%, or 30% wheat DDGS. Results indicated that there was no effect of wheat DDGS on pig growth performance or carcass quality. However, addition of wheat DDGS increased linearly ($P < 0.015$) the indole concentration in the carcasses of the pigs. In conclusion, the SID of AA in maize DDGS produced in Europe is greater than in European wheat DDGS and DDGS produced from mixtures of wheat and maize, but inclusion of 30% wheat DDGS in diets fed to growing-finishing pigs did not affect growth performance or carcass quality.

Key words: amino acid digestibility, carcass characteristics, distillers dried grains with solubles, growth performance, pigs

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INTRODUCTION

Distillers dried grains with solubles (DDGS) is a coproduct of cereal grain fermentation. In the United States, maize is the primary feedstock used in ethanol production, but European ethanol plants may use wheat or maize or combinations of wheat and maize as feedstock (Cozannet et al., 2010a). Digestibility of AA in maize DDGS varies (Stein and Shurson, 2009), but the AA that is most variable in concentration and digestibility is Lys (Cozannet et al., 2010b; NRC, 2012; Rosenfelder et al., 2013). Greater variation in Lys digestibility may be a result of heat damage in some sources of DDGS (Pahm et al., 2008; Stein and Shurson, 2009; Almeida, et al., 2013). Wheat DDGS usually contains more CP and NDF, but less ether extract than maize DDGS, and variability in AA composition and digestibility among sources of wheat DDGS has been reported (Widyaratne and Zijlstra, 2008; Cozannet et al., 2010b; NRC, 2012). The concentration and digestibility of Lys tends to be less in wheat DDGS than in maize DDGS, whereas the opposite is the case for Trp (Stein and Shurson, 2009). As a consequence, the AA composition of DDGS produced from mixtures of maize and wheat depends on the proportion of each cereal grain used. However, the composition and digestibility of AA in DDGS may be influenced not only by the feedstock used in the ethanol plant, but possibly also by the year in which the grain was grown because grain composition may vary from year to year. There are, however, limited data on how these differences influence the digestibility of AA in DDGS (Widyaratne and Zijlstra, 2007, 2008; Nitrayová et al., 2012; Kiarie et al., 2013). Inclusion of wheat DDGS to growing-finishing diets resulted in contradictory effects on growth performance and carcass quality (Stein and Shurson, 2009), which may be a result of incorrect diet formulation because wheat DDGS has low Lys digestibility (Nyachoti et al., 2005). Therefore, an experiment was conducted to test the hypothesis that the standardized ileal digestibility (SID) of AA by growing pigs is different among sources of European DDGS produced from wheat, maize, or wheat–maize mixtures. The second objective was to test the hypothesis that there is no impact on growth performance and carcass quality of growing-finishing pigs of including wheat DDGS in the diet.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois (United States) reviewed and approved the protocol for the AA digestibility experiment, and the Ethical Review Committee of the School of Biosciences at the University of Nottingham (United Kingdom) reviewed and approved the protocol for the growth performance experiment.

Exp 1. Amino Acid Digestibility

Twelve barrows (initial BW: 23.0 ± 2.2 kg) were surgically equipped with a T-cannula in the distal ileum (Stein et al., 1998). Pigs were randomly allotted to a replicated 6 × 6 Latin square design with six diets and six periods and housed individually in pens (1.2 × 1.5 m) with fully slatted tri-bar floors, solid-sided walls, a feeder, and a nipple drinker. Pens were located in a temperature-controlled barn that had forced air fans and a propane heater.

Five European sources of DDGS were used: wheat DDGS from 2011, wheat DDGS from 2012, wheat-80 DDGS (80% wheat and 20% maize), wheat-70 DDGS (70% wheat and 30% maize), and maize DDGS (Table 1). Wheat DDGS from 2011 was manufactured in 2011 using UK wheat that was harvested in 2010. Wheat DDGS from 2012 was manufactured in 2012 using UK wheat that was harvested in 2012. Wheat-80 DDGS was manufactured in 2012 using approximately 80% UK wheat that was harvested in 2012 and approximately 20% maize that was harvested in France in 2012. Wheat-70 DDGS contained approximately 70% wheat and 30% maize that were harvested in Germany in 2012. Maize DDGS was manufactured in Hungary using maize that was harvested in Hungary in 2012. Six diets were prepared in meal form (Tables 2 and 3). Five diets contained cornstarch, sucrose, and 50% of each of the five sources

Table 1. Chemical composition of five European sources of DDGS derived from maize, wheat, or mixtures of maize and wheat, as-fed basis, Exp. 1

	DDGS source				
Item	Wheat DDGS 2011	Wheat DDGS 2012	Wheat-80[1] DDGS	Wheat-70[1] DDGS	Maize DDGS
DM, %	89.53	90.71	90.00	90.25	88.71
CP, %	32.35	34.60	30.67	28.74	29.01
AEE[2], %	5.74	5.19	5.53	6.01	9.60
Ash, %	4.36	5.13	4.53	6.49	4.34
ADF, %	24.49	24.83	21.86	17.89	13.35
NDF, %	33.68	35.24	33.66	30.42	27.13
GE, kcal/kg	4,483	4,549	4,566	4,373	4,636
Indispensable AA, %					
Arg	1.23	1.26	1.09	1.04	1.26
His	0.58	0.62	0.57	0.57	0.76
Ile	1.11	1.16	1.01	0.97	1.05
Leu	2.15	2.24	2.26	2.18	3.45
Lys	0.53	0.53	0.49	0.56	0.84
Met	0.46	0.46	0.43	0.42	0.60
Phe	1.45	1.56	1.36	1.26	1.43
Thr	0.96	0.98	0.89	0.90	1.07
Trp	0.32	0.34	0.28	0.27	0.23
Val	1.40	1.46	1.30	1.25	1.39
All indispensable AA	10.19	10.61	9.68	9.42	12.08
Lys:CP ratio[3], %	1.64	1.53	1.60	1.95	2.90
Dispensable AA, %					
Ala	1.21	1.26	1.36	1.30	2.13
Asp	1.59	1.63	1.53	1.53	1.89
Cys	0.61	0.60	0.52	0.49	0.55
Glu	8.47	9.09	7.11	6.37	5.21
Gly	1.30	1.35	1.19	1.11	1.15
Pro	2.85	3.07	2.56	2.33	2.36
Ser	1.44	1.47	1.29	1.21	1.42
All dispensable AA	17.47	18.47	15.56	14.34	14.71

[1]Wheat-80 DDGS = DDGS derived from 80% wheat and 20% maize; wheat-70 DDGS = DDGS derived from 70% wheat and 30% maize.

[2]AEE = acid hydrolyzed ether extract.

[3]The Lys:CP ratio is calculated by expressing the concentration of Lys in each sample as a percentage of the concentration of CP (Stein et al., 2009).

of DDGS as the only source of protein and AA. An N-free diet that was used to calculate basal endogenous losses of protein and AA was also formulated. Vitamins and minerals were added to all diets to meet or exceed requirements (NRC, 2012). Chromic oxide was included in all diets at 0.4% as an indigestible marker. Pigs were fed diets at 3 times the estimated energy requirement for maintenance (i.e., 197 kcal ME per kg $^{0.60}$; NRC, 2012) in two equal meals per day. Water was available at all times from a nipple drinker.

At the beginning of each period, individual pig weights were recorded to calculate the amount of feed that needed to be fed during the period. Each period was 7 d; the first 5 d was considered a diet adaptation period, but on days 6 and 7, ileal digesta were collected for 8 h, by attaching a plastic bag to the T-cannula via a plastic auto-locking zip-tie (Stein et al., 1998). Bags were removed from the cannula and replaced with an empty bag and zip-tie whenever they were full or every 30 min. Ileal digesta were placed in individual, labeled containers immediately after collection. Containers were stored at −20°C to prevent bacterial breakdown of AA in the ileal digesta. At the end of each collection period, unconsumed feed was removed, and pigs were deprived of feed overnight. The following morning, a new experimental diet was fed.

At the conclusion of each period, ileal digesta were thawed, mixed within diet and animal, and a subsample was collected. Subsamples of ileal digesta were lyophilized and ground prior to chemical analysis. Diets, ingredients, and ileal digesta were analyzed for DM (method 930.15; AOAC Int., 2007), CP (method 990.03; AOAC Int., 2007), and AA (method 982.30 E (a, b, c); AOAC Int., 2007). Diets and ileal digesta were also analyzed

Table 2. Ingredient composition of experimental diets, as-fed basis; Exp. 1

	Diets					
Ingredient, %	Wheat DDGS 2011	Wheat DDGS 2012	Wheat-80[1] DDGS	Wheat-70[1] DDGS	Maize DDGS	N-free
Wheat DDGS from 2011	50.0	–	–	–	–	–
Wheat DDGS from 2012	–	50.0	–	–	–	–
Wheat-80 DDGS	–	–	50.0	–	–	–
Wheat-70 DDGS	–	–	–	50.0	–	–
Maize DDGS	–	–	–	–	50.0	–
Cornstarch	25.5	25.5	25.5	25.5	25.5	67.8
Soybean oil	2.0	2.0	2.0	2.0	2.0	4.0
Sucrose	20.0	20.0	20.0	20.0	20.0	20.0
Limestone	1.4	1.4	1.4	1.4	1.4	0.6
Salt	0.4	0.4	0.4	0.4	0.4	0.4
Monocalcium phosphate	–	–	–	–	–	2.0
Solka Floc[2]	–	–	–	–	–	4.0
Magnesium oxide	–	–	–	–	–	0.1
Potassium carbonate	–	–	–	–	–	0.4
Chromic oxide	0.4	0.4	0.4	0.4	0.4	0.4
Vitamin-mineral premix[3]	0.3	0.3	0.3	0.3	0.3	0.3

[1]Wheat-80 DDGS = DDGS derived from 80% wheat and 20% maize; wheat-70 DDGS = DDGS derived from 70% wheat and 30% maize.

[2]Fiber Sales and Development Corp., Urbana, OH.

[3]Provided the following per kg of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu as copper sulfate and copper chloride, 20 mg; Fe as ferrous sulfate, 126 mg; I as ethylenediamine dihydriodide, 1.26 mg; Mn as manganese sulfate, 60.2 mg; Se as sodium selenite and selenium yeast, 0.3 mg; and Zn as zinc sulfate, 125.1 mg.

Table 3. Chemical composition of experimental diets, as-fed basis; Exp. 1

	DDGS source					
Item	Wheat DDGS 2011	Wheat DDGS 2012	Wheat-80[1] DDGS	Wheat-70[1] DDGS	Maize DDGS	N-free
DM, %	91.49	92.46	91.83	92.27	91.77	91.47
CP, %	17.29	17.65	15.09	14.54	14.94	1.13
Indispensable AA, %						
Arg	0.65	0.63	0.51	0.52	0.63	0.01
His	0.31	0.31	0.27	0.29	0.38	<0.01
Ile	0.60	0.58	0.48	0.49	0.53	0.01
Leu	1.15	1.14	1.10	1.10	1.75	0.04
Lys	0.29	0.27	0.23	0.29	0.42	<0.02
Met	0.23	0.21	0.19	0.20	0.30	<0.01
Phe	0.77	0.79	0.66	0.64	0.72	0.02
Thr	0.51	0.50	0.43	0.45	0.54	0.01
Trp	0.18	0.17	0.14	0.13	0.11	<0.02
Val	0.76	0.74	0.62	0.64	0.70	0.02
Dispensable AA, %						
Ala	0.65	0.65	0.66	0.66	1.08	0.03
Asp	0.85	0.83	0.73	0.78	0.96	0.02
Cys	0.32	0.30	0.25	0.25	0.28	<0.01
Glu	4.51	4.61	3.43	3.23	2.64	0.06
Gly	0.70	0.69	0.58	0.56	0.58	0.01
Pro	1.56	1.58	1.24	1.20	1.19	0.03
Ser	0.76	0.76	0.63	0.61	0.72	0.02

[1]Wheat-80 DDGS = DDGS derived from 80% wheat and 20% maize; wheat-70 DDGS = DDGS derived from 70% wheat and 30% maize.

for chromium (method 990.08; AOAC Int., 2007). Ingredients were analyzed for ADF (method 973.18;AOAC Int., 2007) and NDF (Holst, 1973). Ingredients were analyzed for acid hydrolyzed ether extract by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction

with petroleum ether (method 2003.06; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN).

The apparent ileal digestibility (AID) and the SID of CP and each AA in diets containing each source of DDGS were calculated (Stein et al., 2007). Data were analyzed using the Proc MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The model for analysis of variance included pig and period as random effects and diet as a fixed effect. The LSMeans statement was used to calculate mean values for each diet. The pdiff option in Proc Mixed was used to separate treatment means that were significant. The experimental unit for all analyses was the pig, and an alpha level of 0.05 was used to determine significant differences among means.

Exp. 2. Growth Performance and Carcass Characteristics

A total of 36 commercial hybrid intact barrows (initial BW: 38.3 ± 1.97 kg) were randomly allotted to one of four dietary treatments at the Pig Research Unit at the University of Nottingham. Pigs were individually housed in pens (1.5 × 2.0 m) with solid floors; thus, 36 pens with nine replicate pens per treatment were used. Each pen was equipped with a feeder and a nipple drinker and the room temperature was controlled. Diets and water were available on an ad libitum basis.

The experiment had a two-phase feeding program: growing (BW: 35 to 65 kg) and overall (BW: 35 to 105 kg). Eight diets were formulated: four diets were fed to pigs from approximately 35 to 65 kg and four different diets were fed from 65 to 105 kg (Tables 4–6). The four diets contained 0%, 10%, 20%, or 30% wheat DDGS. Diets were balanced for NE and SID Lys and were formulated and manufactured by AB Agri Group (Peterborough, United Kingdom). All diets were formulated to meet estimates for nutrient requirements for growing pigs (BSAS, 2003).

Pig weights were recorded at the start of the experiment and weekly until the end of the experiment when animals were as close as possible to the final BW of 105 kg. The amount of feed offered to each pen was recorded daily and the amount of feed left in the feeder was recorded weekly. Data were summarized to calculate ADG, total feed intake, ADFI, and G:F ratio for grower pigs (35–65 kg) and for the overall period (35–105kg).

Table 4. Ingredient composition of the growing diets, as-fed basis; Exp. 2

	Wheat DDGS inclusion, %			
Ingredient, %	0	10	20	30
Barley	30.00	23.47	16.93	10.40
Wheat	35.70	38.77	41.85	44.92
Wheat feed[1]	12.50	8.33	4.17	0.00
Soybean meal, 48% CP	13.28	10.34	7.39	4.45
Rapeseed meal	5.00	5.00	5.00	5.00
Vitamin-mineral premix[2]	0.25	0.25	0.25	0.25
L-Lys	0.60	0.78	0.96	1.15
DL_Met	0.06	0.06	0.05	0.05
Thr	0.13	0.14	0.16	0.17
L-Trp	0.00	0.01	0.01	0.02
Vitamin E	0.02	0.02	0.02	0.02
Finase[3]	0.01	0.01	0.01	0.01
Limestone	0.93	1.01	1.08	1.15
Dicalcium phosphate	0.28	0.19	0.09	0.00
Salt	0.38	0.36	0.35	0.33
Sodium bicarbonate	0.35	0.23	0.12	0.00
Soy oil	0.50	0.50	0.50	0.50
Fat	-	0.53	1.06	1.59
Wheat DDGS	-	10.00	20.00	30.00

[1]Wheat feed: coproduct of flour manufacturing from screened wheat. It consists principally of fragments of the outer skin and of particles of grain from which less of the endosperm has been removed than in wheat bran (Ewing, 1997).

[2]The vitamin-micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A, 6,850 IU; vitamin D_3, 2,000 IU; vitamin E, 35 IU; vitamin K, 2 mg; thiamin, 1.5 mg; riboflavin, 3 mg; pyridoxine, 2 mg; vitamin B_{12}, 15 µg; D-pantothenic acid, 8 mg; nicotinic acid, 20 mg; folic acid, 0.3 mg; biotin, 50 µg; Cu as copper sulfate, 15 mg; Fe as ferrous sulfate, 80 mg; I as potassium iodide or calcium iodate, 1 mg; Mn as manganese sulfate, 65 mg; Se as 1-butyl-1-methyl-pyrrolidinium (BMP), 0.25 mg; Zn as zinc sulfate, 65 mg and Mg as magnesium phosphate 1500 mg.

[3]Finase is a bacterial 6-phytase (AB Vista, Marlborough, UK)

Table 5. Ingredient composition of the finishing diets, as-fed basis; Exp. 2

	Wheat DDGS inclusion, %			
Ingredient, %	0	10	20	30
Barley	30.00	27.45	24.89	22.34
Wheat	34.59	35.81	37.04	38.26
Wheat feed[1]	17.50	11.67	5.83	–
Soy bean meal, 48% CP	12.64	9.29	5.95	2.60
Rapeseed meal	2.50	2.50	2.50	2.50
Vitamin-mineral premix[2]	0.25	0.25	0.25	0.25
L-Lys	0.17	0.37	0.57	0.78
L-Thr	–	0.01	0.03	0.04
Vitamin E	0.02	0.02	0.02	0.02
Finase[3]	0.01	0.01	0.01	0.01
Limestone	1.01	1.07	1.14	1.21
Dicalcium phosphate	0.24	0.16	0.08	–
Salt	0.43	0.40	0.36	0.32
Sodium bicarbonate	0.15	0.10	0.06	0.01
Fat	0.50	0.89	1.28	1.67
Wheat DDGS	–	10.00	20.00	30.00

[1]Wheat feed: co-product of flour manufacturing from screened wheat. It consists principally of fragments of the outer skin and of particles of grain from which less of the endosperm has been removed than in wheat bran (Ewing, 1997).

[2]The vitamin-micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A, 6,850 IU; vitamin D_3, 2,000 IU; vitamin E, 35 IU; vitamin K, 2 mg; thiamin, 1.5 mg; riboflavin, 3 mg; pyridoxine, 2 mg; vitamin B_{12}, 15 µg; D-pantothenic acid, 8 mg; nicotinic acid, 20 mg; folic acid, 0.3 mg; biotin, 50 µg; Cu as copper sulfate, 15 mg; Fe as ferrous sulfate, 80 mg; I as potassium iodide or calcium iodate, 1 mg; Mn as manganese sulfate, 65 mg; Se as 1-butyl-1-methyl-pyrrolidinium (BMP), 0.25 mg; Zn as zinc sulfate, 65 mg and Mg as magnesium phosphate 1500 mg.

[3]Finase is a bacterial 6-phytase (AB Vista, Marlborough, United Kingdom).

Table 6. Chemical composition of experimental diets, as-fed basis; Exp. 2

	Grower, wheat DDGS % diet				Finisher, wheat DDGS % diet			
	0	10	20	30	0	10	20	30
DM, %	88.0	88.0	87.7	88.0	86.9	87.0	87.4	87.7
Ash, %	5.0	4.2	4.8	5.0	5.4	5.0	4.9	5.5
CP, %	16.7	16.2	19.2	19.9	16.3	18	17.8	19.7
CF, %	3.9	4.1	3.9	3.8	4.6	4.7	4.8	4.8
Ether extract, %	2.7	3.3	4.5	5.4	2.7	3.6	4.3	4.7
AEE[1], %	3.3	3.8	5.2	6.1	3.5	4.5	5.1	5.7
NDF[2], %	12.1	12.2	13.8	14.5	12.6	13.4	15.4	17.2
Starch, %	32.9	31.8	33.1	34	38.3	36.6	36.3	31.8
Sucrose, %	3.8	3.2	3.3	3.2	3.6	3.6	3.4	2.8
Ca, %	0.81	0.53	0.82	0.89	0.97	0.78	0.78	0.91
P, %	0.44	0.40	0.43	0.40	0.41	0.44	0.41	0.41
Na, %	0.24	0.26	0.22	0.2	0.22	0.23	0.23	0.42
NaCl, %	0.47	0.49	0.47	0.47	0.56	0.53	0.48	0.49
Mg, %	0.15	–	0.16	0.15	0.15	0.16	0.15	0.16
K, %	0.70	0.66	0.68	0.68	0.73	0.76	0.69	0.74
Mn, ppm	64	–	74	59	57	83	56	75
Cu, ppm	18	–	21	25	24	24	17	23
Zn, ppm	99	–	106	92	91	121	92	105

[1]AEE = acid hydrolyzed ether extract.

[2]NDF = neutral detergent fiber.

On the last day of the experiment, animals were transferred to the University of Nottingham experimental EU-licensed abattoir without a preslaughter starvation period and they were all slaughtered by electrical stunning followed by exsanguination. The whole carcass was scalded and dehaired. Carcass pH was monitored to assess evidence of Pale Soft Exudative (PSE) meat by an InLab 427 Combination

pH Puncture Electrode with a SG2-ELK – SevenGo pH meter (Mettler Toledo Inc., Mississauga, ON). The probe was inserted into exposed longissimus in the right side of the carcass 45 min after slaughter. Carcasses were split and stored at 4°C for 24 h at which point pH was again recorded. Subcutaneous fat depth (P2) was measured at a position level with the head of the last rib at 65 mm from the dorsal midline. Carcass length was measured from the anterior edge of the *Symphysis pubis* to the vascular impression on the anterior edge of the first rib. A sample of shoulder backfat (~100 × 50 mm) was also collected from each animal at slaughter for indole and skatole analyses using the Likens–Nickersin method (Annor-Frempong et al., 1997) to assess the possible effect of wheat DDGS on concentrations of indole and skatole in pig meat.

Data for individual pig BW and daily feed allotments were summarized at the conclusion of the experiment to calculate data for ADG, ADFI, and G:F for each pig. These calculations were completed for the grower phase (35–65 kg) and for the overall phase (35–105 kg).

Proximate Analysis of the Diets

Diets were analyzed for DM by recording the weight of diet samples after heating at 103–105°C for 2 h and 45 min, and ash was analyzed by incinerating samples at 510°C for 4 h. Diets were also analyzed for N using a LECO FP-528 Nitrogen Analyser (LECO Corporation, Saint Joseph, MI) and CP was calculated as N × 6.25. Crude fiber (CF) of diets was analyzed using an Ankom Analyzer (Ankom Technology, Macedon, NY). Diets were also analyzed for NDF by enzymatic gravimetry, where the starch in the samples was converted to soluble sugars by the action of α-amylase after de-fatting of the sample with petroleum. The residue was then boiled with a neutral solution and the soluble nutrients were separated and the remaining insoluble matter was designated as NDF.

Starch was determined by two determinations; first the samples were treated whilst warm, with dilute hydrochloric acid, after clarification and filtering, the optical rotation of the solution was measured by polarimetry. Second, the samples were extracted with 40% denatured ethanol, after acidifying the filtrate with hydrochloric acid, clarifying and filtering, the optical rotation was measured under the same conditions as the first determination. The difference between the two readings, multiplied by a known factor, gave the starch content of the sample.

Total sugars were determined by the Luff Schoorl method where sugars were extracted from the sample by shaking with water, then the solution was clarified with Carrez reagent, filtered and an aliquot of the extract was heated with dilute hydrochloric acid to convert any disaccharides to reducing sugars. These sugars were then determined by the Luff Schoorl Copper reduction (titration) method whereby the sample extract was refluxed with Luff Schoorl reagent and remaining excess copper (II) ions were titrated with sodium thiosulfate volumetric solution. A blank titration using only the Luff Schoorl reagent was also included in the analysis. A table relating the difference between the blank and sample titration values was used to give the equivalent concentration of the reducing sugar glucose in the solution. A factor of 0.95 was applied to this value to give the equivalent result as sucrose.

Acid hydrolyzed fat was analyzed as petroleum ether extract, which was obtained by the continuous extraction of the sample with warm light petroleum ether at 40 to 60°C with subsequent removal of the solvent by evaporation. The residual was then boiled in hydrochloric acid to release bound fat and the digest was filtered with a filter aid and washed until neutral.

Calcium, P, Na, Mg, K, Mn, and Zn were determined using the inductively coupled plasma optical emission spectrometry (ICP-OES) with a Perkin Elmer Optima 5300DV (PerkinElmer, Llantrisant, United Kingdom). Samples were ashed at 510°C and then digested in a mixture of nitric and hydrochloric acids. After dilution and filtration, the resulting solution was aspirated into an ICP-OES and the optical emission measured at the selected wavelength for that element against standards of known concentration covering the expected range of inclusion. Salt was determined by electrochemical determination of chloride, the samples were extracted with deionised water, and the resultant solution was analyzed using the chloride meter. The reading was taken as the chloride content of the solution.

Statistical Analysis

Data were analyzed by ANOVA using a fully randomized design Genstat v16.1 (VSN International Ltd., Hemel Hempstead, United Kingdom) with the pen as the experimental unit. The statistical model included the fixed effect of wheat DDGS. Contrast statements were used to test the linear and quadratic effects of the wheat DDGS inclusion.

Statistical significance and tendencies were considered at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

RESULTS

Exp. 1. Amino Acid Digestibility

All pigs were healthy for the duration of the experiment. The AID for CP was greater ($P < 0.05$) in maize DDGS, wheat-80 DDGS, and wheat DDGS from 2012 than in wheat-70 DDGS (Table 7). There was no difference in AID for CP between wheat DDGS from 2011 and wheat DDGS from 2012.

The AID for all indispensable AA except Trp and the mean of all indispensable AA was greater ($P < 0.05$) in maize DDGS than in all other ingredients. For Trp, the AID in wheat-80 DDGS, wheat DDGS from 2011, and wheat DDGS from 2012 was greater ($P < 0.05$) than in wheat-70 DDGS, but the AID of Trp in wheat-70 DDGS was not different from maize DDGS. The mean AID for indispensable AA in wheat-70 DDGS was less ($P < 0.05$) than in maize DDGS and wheat-80 DDGS, but not different from the mean AID for indispensable AA in wheat DDGS from 2011 and wheat DDGS from 2012. The AID for all AA was greater ($P < 0.05$) in maize DDGS than in all other DDGS sources used in this experiment.

The SID for CP was greater ($P < 0.05$) in maize DDGS than in wheat DDGS from 2011, wheat DDGS from 2012, and wheat-70 DDGS, but not different from the SID for CP in wheat-80 DDGS (Table 8). The SID for all indispensable AA except Trp was greater ($P < 0.05$) in maize DDGS than in all other DDGS sources used in this experiment. For Trp, the SID in wheat-80 DDGS, wheat DDGS from 2011, and wheat DDGS from 2012 was not different from maize DDGS, but was greater ($P < 0.05$) than in wheat-70 DDGS. For His, Thr, Val, and the mean of indispensable AA, the SID was greater ($P < 0.05$) in wheat-80 DDGS than in wheat-70 DDGS, but not different from the SID in wheat DDGS from 2011 and wheat DDGS from 2012. The SID for all indispensable AA except Ile and Trp in wheat-70 DDGS was not different from the values calculated for wheat DDGS from 2011 and wheat DDGS from 2012. The SID for all AA was greater ($P < 0.05$) in wheat-80 DDGS than in wheat-70 DDGS, but the SID for all AA in wheat-70 DDGS was not different from the SID in wheat DDGS from 2011 and wheat DDGS from 2012.

Table 7. Apparent ileal digestibility by growing pigs of CP and AA in five European sources of DDGS derived from maize, wheat, or mixtures of wheat and maize, Exp.1

	DDGS source						
Item	Wheat DDGS 2011	Wheat DDGS 2012	Wheat-80[1] DDGS	Wheat-70[1] DDGS	Maize DDGS	SEM	*P* value
CP, %	51.87^{bc}	53.44^{ab}	53.40^{ab}	48.22^{c}	57.43^{a}	2.00	0.01
Indispensable AA, %							
Arg	66.08^{b}	66.79^{b}	65.93^{b}	65.66^{b}	76.05^{a}	3.26	<0.01
His	62.86^{bc}	63.19^{bc}	65.22^{b}	60.53^{c}	74.06^{a}	1.66	<0.01
Ile	63.27^{b}	62.70^{b}	64.28^{b}	57.39^{c}	69.91^{a}	1.64	<0.01
Leu	68.70^{c}	68.09^{c}	73.36^{b}	68.43^{c}	83.76^{a}	1.35	<0.01
Lys	21.27^{b}	15.91^{b}	18.75^{b}	19.94^{b}	50.61^{a}	3.71	<0.01
Met	66.40^{bc}	64.64^{c}	68.23^{b}	65.17^{bc}	80.57^{a}	1.50	<0.01
Phe	68.94^{b}	68.20^{bc}	69.59^{b}	65.22^{c}	74.05^{a}	1.66	<0.01
Thr	50.77^{b}	49.83^{bc}	52.15^{b}	45.91^{c}	60.61^{a}	2.09	<0.01
Trp	54.64^{a}	51.54^{ab}	53.46^{a}	43.71^{c}	47.22^{bc}	2.23	<0.01
Val	60.46^{bc}	59.24^{bc}	61.78^{b}	57.16^{c}	69.72^{a}	1.75	<0.01
Mean	61.42^{bc}	60.80^{bc}	63.49^{b}	58.65^{c}	73.22^{a}	1.69	<0.01
Dispensable AA, %							
Ala	43.50^{c}	42.55^{c}	53.23^{b}	50.29^{b}	70.16^{a}	2.51	<0.01
Asp	39.81^{bc}	38.32^{c}	44.84^{b}	41.19^{bc}	61.61^{a}	2.58	<0.01
Cys	61.94^{b}	61.53^{b}	62.61^{b}	55.69^{c}	67.98^{a}	1.82	<0.01
Glu	80.91^{ab}	91.99^{a}	81.53^{a}	76.80^{c}	79.21^{b}	0.98	<0.01
Gly	28.25^{a}	29.12^{a}	29.02^{a}	17.57^{b}	19.23^{ab}	5.39	<0.05
Ser	64.79^{b}	66.25^{b}	66.94^{b}	60.01^{c}	73.12^{a}	1.68	<0.01
Mean	66.06^{a}	67.10^{a}	67.46^{a}	61.37^{b}	68.19^{a}	1.58	<0.01
All AA	64.13^{b}	64.55^{b}	65.60^{b}	60.18^{c}	70.66^{a}	1.60	<0.01

$^{a-c}$Within a row, means without a common superscript differ ($P < 0.05$).

Each least square mean represents 12 observations.

[1]Wheat-80 DDGS = DDGS derived from 80% wheat and 20% maize; wheat-70 DDGS = DDGS derived from 70% wheat and 30% maize.

Table 8. Standardized ileal digestibility by growing pigs of CP and AA in five European sources of DDGS derived from maize, wheat, or mixtures of wheat and maize, Exp.1

	DDGS source						
Item	Wheat DDGS 2011	Wheat DDGS 2012	Wheat-80[1] DDGS	Wheat-70[1] DDGS	Maize DDGS	SEM	*P* value
CP, %	61.53[b]	63.00[b]	64.50[ab]	59.79[b]	68.64[a]	2.00	0.01
Indispensable AA, %							
Arg	72.63[b]	73.63[b]	74.31[b]	73.93[b]	82.83[a]	3.26	<0.01
His	68.02[bc]	68.40[bc]	71.16[b]	66.09[c]	78.28[a]	1.66	<0.01
Ile	68.00[b]	67.64[b]	70.20[b]	63.22[c]	75.27[a]	1.64	<0.001
Leu	72.89[c]	72.37[c]	77.76[b]	72.85[c]	86.52[a]	1.35	<0.01
Lys	32.59[b]	28.20[b]	33.07[b]	31.36[b]	58.45[a]	3.71	<0.01
Met	70.23[bc]	68.88[c]	72.89[b]	69.62[bc]	83.51[a]	1.50	<0.01
Phe	75.62[bc]	74.77[bc]	77.41[b]	73.32[c]	81.21[a]	1.66	<0.01
Thr	60.78[bc]	60.14[bc]	64.05[b]	57.34[c]	70.09[a]	2.09	<0.01
Trp	62.19[a]	59.63[a]	63.21[a]	54.26[b]	59.62[a]	2.21	<0.01
Val	65.63[bc]	64.61[bc]	68.14[b]	63.35[c]	75.35[a]	1.75	<0.01
Mean	67.49[bc]	67.06[bc]	70.67[b]	65.67[c]	78.67[a]	1.69	<0.01
Dispensable AA, %							
Ala	52.84[c]	51.98[c]	62.46[b]	59.56[b]	75.79[a]	2.51	<0.01
Asp	48.00[c]	46.80[c]	54.42[b]	50.20[bc]	68.88[a]	2.58	<0.01
Cys	67.80[b]	67.85[b]	70.14[b]	63.26[c]	74.70[a]	1.81	<0.01
Glu	82.89[a]	83.96[a]	84.16[a]	79.60[b]	82.62[a]	0.98	<0.01
Gly	49.66	51.07	54.96	44.56	45.15	5.39	0.22
Ser	71.04[bc]	72.56[b]	74.50[b]	67.85[c]	79.73[a]	1.68	<0.01
Mean	71.66[ab]	72.73[a]	74.44[a]	68.60[b]	75.18[a]	1.58	<0.01
All AA	69.93[bc]	70.43[bc]	72.66[b]	67.32[c]	76.90[a]	1.60	<0.01

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).

Each least square mean represents 12 observations. Values for standardized ileal digestibility were calculated by correcting apparent ileal digestibility values for basal endogenous losses (g/kg of DMI), which were determined by feeding pigs a N-free diet; CP, 18.24; Arg, 0.47; His, 0.17; Ile, 0.31; Leu, 0.53; Lys, 0.36; Met, 0.10; Phe, 0.56; Thr, 0.56; Trp, 0.15; Val, 0.43; Ala, 0.66; Asp, 0.76; Cys, 0.21; Glu, 0.98; Gly, 1.64; Ser, 0.52.

[1]Wheat-80 DDGS = DDGS derived from 80% wheat and 20% maize; wheat-70 DDGS = DDGS derived from 70% wheat and 30% maize.

Table 9. Growth performance of pigs fed diets containing increasing levels of wheat DDGS; Exp. 2

	Wheat DDGS inclusion, %					*P* value		
Item	0	10	20	30	SEM	Treatment	Linear	Quadratic
Phase I (BW: 35 to 65 kg)								
ADG, kg	1.03	1.10	1.08	1.04	0.04	0.259	0.939	0.063
Total feed intake, kg	58	56	56	60	4.6	0.794	0.776	0.341
ADFI, kg	2.01	2.03	1.99	2.04	0.31	0.987	0.888	0.913
G:F	0.52	0.54	0.54	0.50	0.07	0.793	0.775	0.340
Overall (BW: 35 to 105 kg)								
ADG, kg	1.09	1.14	1.13	1.04	0.06	0.286	0.357	0.090
Total feed intake, kg	188	190	182	191	5.9	0.438	0.989	0.374
ADFI, kg	2.72	2.88	2.72	2.63	0.282	0.329	0.310	0.211
G:F	0.40	0.39	0.41	0.39	0.02	0.439	0.991	0.373

Data are means of nine observations per treatment.

Exp. 2. Growth Performance and Carcass Characteristics

There were no differences in growth performance (ADG, ADFI, and FCR) among pigs fed experimental diets in phase I (BW: 35 to 65 kg) or for the overall phase (BW: 35 to 105 kg; Table 9). However, there was a trend for ADG in phase I (quadratic, $P = 0.063$) and for the overall phase (quadratic, $P = 0.090$) for pigs fed diets containing 10% wheat DDGS to have the greatest ADG.

There were no differences in carcass quality (dressing percentage, P2, length, pH, and skatole)

Table 10. Carcass quality of pigs fed diets containing increasing levels of wheat DDGS, Exp. 2

	Wheat DDGS inclusion, %					*P* value		
Item	0	10	20	30	SEM	Treatment	Linear	Quadratic
Dressing percentage, %	74.2	74.2	74.9	74.1	0.69	0.619	0.820	0.460
P2[1], mm	8	7	8	6	1.3	0.540	0.516	0.528
Length, mm	842	845	826	845	9.9	0.173	0.705	0.246
pH								
45 m pH	6.2	6.2	6.2	6.3	0.08	0.761	0.368	0.661
24 h pH	5.8	5.8	5.9	5.9	0.09	0.404	0.186	0.673
Change in pH	0.4	0.5	0.3	0.3	0.13	0.716	0.709	0.565
Skatole, µg/g	0.037	0.032	0.041	0.032	0.017	0.940	0.897	0.885
Indole, µg/g[2]	0.021	0.019	0.047	0.033	0.008	0.005	0.015	0.249

Data are means of nine observations per treatment.

[1]P2 = subcutaneous fat depth.

[2]Response in amount of indole (Y, µg/g) to increasing levels of DDGS (X, %) is described by the linear equation: Y = 0.0006X + 0.0203; R^2 = 0.399.

among pigs fed experimental diets (Table 10). However, addition of wheat DDGS increased linearly ($P < 0.05$) the indole concentration in the carcasses of the pigs.

DISCUSSION

Composition of Distillers Dried Grains with Solubles

The concentration of DM in maize DDGS is in agreement with reported values for DM in maize DDGS produced in the United States (Stein et al., 2006, 2009; Pedersen et al., 2007). The concentration of DM in wheat DDGS from 2011 and wheat DDGS from 2012 was in agreement with the concentration of DM in wheat DDGS reported by Cozannet et al. (2010b), but was slightly less than the range of DM in wheat DDGS reported by Nyachoti et al. (2005). The concentration of DM in wheat-80 DDGS and wheat-70 DDGS was not different and the DM concentration in wheat-70 DDGS is in agreement with published values (Ayoade et al., 2012; Kiarie et al., 2013). To the best of our knowledge, there are no published values for composition of DDGS derived from a mixture of 80% wheat and 20% maize.

The concentration of CP in wheat DDGS from 2011 was within the range of concentrations of CP in wheat DDGS reported by Nyachoti et al. (2005), but was less than the concentration of CP in wheat DDGS reported by Stein (2012). The composition of AA in wheat DDGS from 2011 and wheat DDGS from 2012 was less than reported values (Stein, 2012). The Lys:CP ratio for wheat DDGS from 2011 (1.64%) and for wheat DDGS from 2012 (1.53%) was less than the values (1.99% and 1.91%) calculated from the NRC (2012) and Cozannet et al. (2010b), respectively, but were in agreement with the value (1.59%) reported by Stein and Shurson (2009). The concentration of CP in wheat DDGS from 2011 and wheat DDGS from 2012 was greater than the concentration of CP in maize DDGS, which was expected. The concentration of CP in maize DDGS was greater than the concentration of CP in maize DDGS reported by Stein and Shurson (2009) and Kiarie et al. (2013), but was within the range of concentrations of CP in maize DDGS reported by Pedersen et al. (2007). The Lys:CP ratio for maize DDGS (2.90%) indicated that the maize DDGS used in this experiment was not heat damaged (Stein, 2007). The composition of AA in maize DDGS was in agreement with previously reported values for the composition of AA in maize DDGS (NRC, 2012; Stein, 2012). The concentration of CP in wheat-70 DDGS was less than reported values for concentration of CP in DDGS derived from a 70:30 wheat–corn mixture (Yang et al., 2010; Azarfar et al., 2012).

The concentrations of ADF and NDF in wheat DDGS from 2011 and from 2012 were greater than the concentrations of ADF and NDF in wheat DDGS reported by Nyachoti et al. (2005), Cozannet et al. (2010b), and Stein (2012). The concentration of ADF and NDF in wheat-70 DDGS was less than the concentration of ADF and NDF in wheat-80 DDGS, which was expected because there is a greater concentration of wheat in the wheat-80 DDGS and wheat has a greater concentration of ADF and NDF compared with maize (NRC, 2012). The concentration of ADF in wheat-70 DDGS was less than the concentration of ADF in DDGS derived from a 7:3 wheat–corn mixture reported by Azarfar et al. (2012). However, the

concentration of NDF in wheat-70 DDGS was less than the concentration of NDF in DDGS derived from a 7:3 wheat–corn mixture reported by Azarfar et al. (2012), but was in agreement with the concentration of NDF in DDGS derived from a 7:3 wheat–corn mixture reported by Yang et al. (2010). Wheat-70 DDGS and wheat-80 DDGS had ADF and NDF concentrations that were intermediately between the values for wheat DDGS from 2011, wheat DDGS from 2012, and maize DDGS.

Wheat DDGS from 2012 was from a difficult harvest in the United Kingdom that produced wheat with low bushel weights and low starch content; however, wheat DDGS from 2012 contained nutrients in concentrations that were not different from that of wheat DDGS from 2011. This observation indicates that the bushel weight of the wheat grain may not influence the composition of DDGS produced after starch has been converted to ethanol.

The GE in wheat DDGS from 2011 and wheat DDGS from 2012 was less than reported values (Nyachoti et al., 2005; Nitrayová et al., 2012; Stein, 2012). The GE in wheat-70 DDGS was less than the GE in wheat-80 DDGS and was less than the published values of GE in DDGS derived from wheat–maize mixtures (Ayoade et al., 2012; Kiarie et al., 2013). The GE in maize DDGS was also less than reported values of GE in maize DDGS (Stein et al., 2009; NRC, 2012; Stein, 2012).

Crude Protein and Amino Acid Digestibility

The SID of CP in wheat DDGS from 2011 and wheat DDGS from 2012 was slightly less than reported values (Cozannet et al., 2010b). The SID of each AA in wheat DDGS from 2011 and wheat DDGS from 2012 was also less than the SID of each AA in Canadian wheat DDGS reported by Widyaratne and Zijlstra (2007); however, the SID of each AA except Ala and Gly was within the range reported by Cozannet et al. (2010b) who also used European wheat DDGS. For wheat DDGS, the SID of Lys is most variable as indicated by a greater range of SID values (Cozannet et al., 2010b; Rosenfelder et al., 2013). The SID of all AA in wheat DDGS from 2011 was not different from the SID of all AA in wheat DDGS from 2012, which indicates that the digestibility of AA was not compromised by the poor quality of wheat from the 2012 harvest.

The SID of all AA except Arg, Lys, Met, Trp, Val, Ala, and Gly was greater in wheat-80 DDGS than in wheat-70 DDGS, but the SID of all AA in wheat-70 DDGS was less than the SID of all AA in DDGS derived from a 70:30 wheat–corn mixture reported by Yang et al. (2010). To the best of our knowledge, there are no published values for SID of AA in wheat DDGS derived from an 80:20 wheat–maize mixture.

The SID of all AA except Trp, Glu, and Gly was greater in maize DDGS compared with wheat DDGS from 2011 and from 2012. This may be a result of the greater ADF concentration in the wheat DDGS compared with maize DDGS. Greater concentrations of ADF reduce digestibility of AA by restricting access for digestive enzymes (Cozannet et al., 2010b; Rosenfelder et al., 2013). In maize DDGS, the SID of all AA except Lys, Trp, Ala, and Gly was comparable to published values (NRC, 2012; Almeida et al., 2013). The SID of Lys in maize DDGS was less than reported values (Stein et al., 2006; Almeida et al., 2013). The mean of indispensable AA in maize DDGS was similar to reported values (Stein et al., 2006; Almeida et al., 2013). Maize DDGS had greater SID of most AA compared with wheat DDGS and wheat DDGS derived from a mixture of wheat and maize.

Growth Performance and Carcass Quality of Pigs Fed Diets Containing Wheat DDGS

The objective of Experiment 2 was to examine if increasing inclusion of wheat DDGS in diets that were balanced for NE and SID Lys affects growth performance and carcass quality in grower and finisher pigs. Results demonstrate that there were no detrimental effects from the use of wheat DDGS in diets for growing-finishing pigs. Results are partially in agreement with Widyaratne and Zijlstra (2007), who observed that inclusion of 25% wheat DDGS in a wheat- and field pea-based diet fed to pigs from 50 to 85 kg did not affect ADG or FCR, but reduced ADFI. Wheat DDGS contains more fiber than maize or wheat (Emiola et al., 2009), which sometimes has a negative impact on feed intake of pigs, but that was not observed in the present study. This observation is in agreement with observations that growing pigs fed 10% wheat DDGS did not differ in growth performance compared with pigs fed a conventional diet (Woyengo et al., 2016). In contrast, inclusion of 0%, 5%, 10%, 15%, or 20% wheat DDGS in weaned pigs in a wheat-SBM basal diet linearly reduced the ADG and feed efficiency (Wang et al., 2016) and feed intake (Avelar et al., 2010). Reduced ADG and ADFI were also observed with the inclusion of up to 25% wheat DDGS in diets for growing pigs (Thacker, 2006) or

in diets for growing-finishing pigs (Widyaratne and Zijlstra, 2008). It is possible that the reason for the negative results for wheat DDGS in some diets fed to pigs is that diets were formulated based on total AA in wheat DDGS, because wheat DDGS has a low Lys digestibility (Nyachoti et al., 2005; Lan et al., 2008).

The observation that wheat DDGS did not affect dressing percentage is in contrast with Thacker (2006) who reported that 25% wheat DDGS reduced dressing percentage. The lack of an impact of wheat DDGS subcutaneous fat depth is in agreement with observations from studies with corn DDGS (Whitney et al., 2006; Wu et al., 2016). Rate of glycolysis postmortem is linked to incidence of PSE meat with an increased risk associated with a rapid pH decline postmortem. In contrast, if the pH decline is too slow, there is increased risk of dark-firm-dry meat (Warriss, 2000). However, results from this experiment indicate that there was no risk of either PSE or dark-firm-dry meat associated with inclusion of wheat DDGS in the diets, which is also in agreement with data from Whitney et al. (2006).

Indole is synthesized in the large intestine from tryptophan (Jensen et al., 1995) and together with skatole contributes to offensive odors during cooking of pig meats (Lundström et al., 1988; Moss et al., 1993). However, the observation that skatole concentrations were below levels associated with off-odors and flavors in pork (Annor-Frempong et al., 1997) indicate that wheat DDGS does not affect skatole levels.

CONCLUSIONS

The nutrient composition and SID of AA in wheat DDGS from 2012 were not different from that of wheat DDGS from 2011 indicating that low bushel weight of wheat does not affect the quality of wheat DDGS. Maize DDGS had greater SID of AA compared with both wheat DDGS sources. The nutrient composition and SID of AA in wheat-70 DDGS and wheat-80 DDGS were intermediate between maize DDGS and both wheat DDGS sources. Up to 30% wheat DDGS may be included in balanced diets for growing-finishing pigs without affecting growth performance or carcass quality with the exception that carcass indole concentrations are increased.

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