Nutritional value of wheat and corn distiller's dried grain with solubles: Digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs

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Widyaratne, G. P. and Zijlstra, R. T. 2007. **Nutritional value of wheat and corn distiller's dried grain with solubles: Digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs.** Can. J. Anim. Sci. **87**: 103–114. Two experiments were conducted to evaluate the nutritional value of distiller's dried grains with solubles (DDGS) samples derived from corn, wheat and a wheat/corn blend (4:1). Specifically, the digestibility and digestible contents of energy, amino acids (AA) and P, N and P excretion, and growth performance were determined in grower-finisher pigs. In exp. 1, 12 ileal cannulated barrows (64.6 ± 6.4 kg) had restricted access (2.6 × maintenance) to a wheat-control diet or one of three diets containing 40% DDGS sample of corn, wheat or wheat/corn origin that replaced wheat. For energy, apparent total tract digestibility was highest for wheat (85%; $P < 0.05$) and did not differ among the DDGS samples (77 to 79%; $P > 0.10$). Total tract digestible energy (DE) was higher for corn DDGS (4292 kcal kg^{-1} DM; $P < 0.05$) than wheat/corn DDGS, wheat DDGS and wheat samples (4038, 4019 and 3807). For lysine, apparent ileal digestibility (AID) was highest for wheat (71%; $P < 0.05$) and did not differ among DDGS samples (59 to 63%; $P > 0.10$). The AID lysine content was highest for corn DDGS (0.51% DM; $P < 0.05$), intermediate for wheat/corn DDGS and wheat DDGS (0.45 and 0.42), and lowest for wheat (0.37%). For P, total tract digestibility was lowest for wheat (15%; $P < 0.05$) and did not differ among DDGS samples (53 to 56%; $P > 0.10$). Total N excretion was highest for wheat/corn DDGS and wheat DDGS (55 and 58 g d^{-1}; $P < 0.05$), intermediate for corn DDGS (44) and lowest for wheat (36). Total P excretion did not differ among DDGS (11 g d^{-1}) and was lowest for wheat (8; $P < 0.05$). In exp. 2, 100 pigs (52.0 ± 3.3 kg) were fed a wheat-pea control diet or one of three diets containing 25% of the three DDGS samples (3.375 Mcal DE kg^{-1}; 2.50 g SID lysine $Mcal^{-1}$ DE) for 5 wk. Overall, average daily feed intake (ADFI) and daily gain (ADG) were higher for pigs fed the wheat control diet than the DDGS-containing diets ($P < 0.05$), but feed efficiency did not differ ($P > 0.10$). In summary, the digestible nutrient content of wheat DDGS is lower than corn DDGS and higher than wheat. Following pre-characterization of digestible nutrient profile, feeding DDGS reduced growth performance indicating that further research is required to improve the nutritional value of DDGS.

Key words: Distiller's dried grains with solubles, pig, digestibility, energy, amino acid

Widyaratne, G. P. et Zijlstra, R. T. 2007. **Valeur nutritive des drèches de distillerie de blé et de maïs enrichies d'extraits solubles : digestibilité et concentration de l'énergie, des acides aminés et du phosphore digestibles, excrétion des éléments nutritifs et croissance des porcs d'engrais-finition**. Can. J. Anim. Sci. **87**: 103–114. Les auteurs ont effectué deux expériences afin d'estimer la valeur nutritive des drèches de distillerie de maïs, de blé et d'un mélange blé/maïs (4:1) enrichies d'extraits solubles (DDES). Plus précisément, ils ont quantifié la digestibilité et la fraction digestible de l'énergie, des acides aminés et du P, l'excrétion de N et de P, ainsi que le taux de croissance de porcs d'engrais-finition. Dans la première expérience, 12 castrats canulés à l'iléon (64,6 ± 6,4 kg) ont eut un accès limité (2,6 × ration d'entretien) à une ration témoin à base de blé ou à l'une de trois rations renfermant 40 % de DDES de maïs, de blé ou du mélange blé/maïs. La digestibilité apparente de l'énergie pour l'ensemble du système digestif était plus élevée pour le blé (85 %; $P < 0,05$), sans variation entre les divers types de DDES (77 à 79 %; $P > 0,10$). La concentration d'énergie digestible (ED) dans le tractus intestinal était plus élevée pour les DDES de maïs (4 292 kcal par kg de matière sèche; $P < 0,05$) que pour celles de blé/maïs, les DDES de blé et le blé (4 038, 4 019 et 3 807, respectivement). Dans le cas de la lysine, la meilleure digestibilité apparente dans l'iléon (DAI) a été relevée pour le blé (71 %; $P < 0,05$), mais ce paramètre ne variait pas avec le type de DDES (59 à 63 %; $P > 0,10$). Les DDES de maïs contenaient le plus de lysine à DAI (0,51 % de matière sèche; $P < 0,05$), alors que celles de blé/maïs et de blé en contenaient une quantité moyenne (0,45 et 0,42 %

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Abbreviations: **AA,** amino acid; **ADF,** acid detergent fibre; **ADFI**, average daily feed intake; **ADG**, average daily gain; **AID**, apparent ileal digestibility; **BW,** body weight; **CP**, crude protein; **DDGS**, distiller's dried grains with solubles; **DE**, digestible energy; **DM**, dry matter; **IP,** inositol phosphate; **NDF,** neutral detergent fibre; **NPN**, non-protein N; **NSP**, non-starch polysaccharide; **SEM**, standard error of the mean; **SID**, standardized ileal digestibility

respectivement), le blé arrivant bon dernier (0,37 %). La digestibilité du P dans le tube digestif était plus faible pour le blé (15 %; $P < 0,05$) et était la même pour les différentes sortes de DDES (53 à 56 %; $P > 0,10$). Ce sont les DDES de blé/maïs et de blé qui entraînent la plus forte excrétion de N (55 et 58 g par jour; $P < 0,05$); les DDES de maïs se situent à mi-chemin (44), l'excrétion de la plus faible quantité de N étant attribuable au blé (36). La quantité totale de P excrétée ne varie pas avec le type de DDES (11 g par jour), la valeur la plus faible ayant été observée pour le blé (8; $P < 0,05$). Dans le cadre de la deuxième expérience, les auteurs ont nourri 100 porcs (52,0 ± 3,3 kg) avec une ration témoin à base de blé et de pois ou une de trois rations expérimentales renfermant 25 % des trois types de DDES (3,375 Mcal de ED par kg; 2,50 g de lysine à digestibilité normalisée dans l'iléon par Mcal de ED) pendant 5 semaines. Dans l'ensemble, la prise alimentaire quotidienne moyenne et le gain quotidien moyen étaient plus élevés chez les sujets recevant la ration témoin que chez ceux nourris avec les rations contenant des DDES ($P < 0,05$), toutefois l'indice de consommation était le même dans tous les cas ($P > 0,10$). Pour récapituler, les DDES de blé renferment moins d'éléments nutritifs digestibles que les DDES de maïs mais elles en contiennent plus que le blé. Une fois le profil des éléments nutritifs digestibles connu, on remarque que l'engraissement des animaux avec des DDES réduit le taux de croissance, signe qu'on devrait entreprendre d'autres recherches en vue d'améliorer la valeur nutritive de cet aliment.

Mots clés: DDES, porc, digestibilité, énergie, acides aminés

Distiller's dried grains with solubles (DDGS) is a by-product from the cereal grain-based ethanol and alcohol beverage industries (Newland and Mahan 1990). With the rapid growth of the ethanol industry, increasing quantities of DDGS are available for livestock rations, including DDGS produced in western Canada from wheat or corn. In general, DDGS has higher concentrations of nutrients such as protein, fat, vitamins, minerals, and fibre than its parent grain. These nutrients are concentrated due to the removal of most of the cereal starch as ethanol and carbon dioxide during the fermentation process (Weigel et al. 1997).

Product variability and lack of information about the nutritional value of DDGS from different sources were primary reasons for the initial reluctance of using corn DDGS in swine diets. In addition, reduced AA digestibility (Wahlstrom et al. 1970), and an AA profile that is not well suited for pigs (Cromwell et al. 1983) were concerns. Due to the construction of new ethanol plants with modern fermentation and drying technologies in the upper Midwest, the nutritional value of corn DDGS for swine was re-addressed, indicating that high-quality corn DDGS that is presumed to be less variable in terms of nutrient content has become available for the livestock industry (Shurson et al. 2000; Spiehs et al. 2002; Whitney and Shurson 2004); however, the digestible nutrient content of corn DDGS remains to be verified. In contrast, the nutritional value of wheat DDGS for swine has never been described; therefore, its potential for the swine industry is not documented. The continuously increasing supply of corn DDGS and wheat DDGS suggests that evaluation of their nutritional value for swine is worthwhile to support development of cost-effective feeding programs. For any feed ingredient for swine, an understanding of the digestible nutrient content is critical to achieve accurate diet formulation. In addition, nutrient excretion is a major concern for the swine industry due to its potential impact on the environment, and the effects of DDGS on nitrogen (N) and phosphorus (P) excretion patterns should be evaluated. The effects of DDGS on swine growth performance should also be described, because the high fibre content in DDGS may reduce nutrient digestibility and voluntary feed intake, and thereby growth performance.

The objectives of the present study were to determine the energy, AA and P digestibility and digestible nutrient content of DDGS produced from wheat and corn, to evaluate the effect of DDGS on N and P excretion patterns, and to determine whether feeding diets containing DDGS results in growth performance equal to grower-finisher pigs fed a wheat-based control diet.

MATERIALS AND METHODS

Ingredients

Three DDGS samples were obtained from two sources: corn DDGS from an unknown US origin via a commercial feed mill (Federated Co-op, Saskatoon, SK), and wheat DDGS and wheat/corn DDGS from an ethanol plant (Mohawk Canada, Minnedosa, MB) that used Hard Red Spring wheat as a feedstock. Occasionally, wheat and corn are fermented together to overcome periods of limited wheat supply, and the feedstocks wheat and corn were blended and fermented in a 4:1 ratio for production of the specific wheat/corn DDGS used in this experiment. The same three batches of DDGS were used in the digestibility and performance studies.

Experimental Protocol

The animal protocols were approved by the University of Saskatchewan Committee of Animal Care and Supply and followed principles established by the Canadian Council on Animal Care (1993). Two experiments were conducted at Prairie Swine Centre Inc. (Saskatoon, SK).

Exp. 1 – Digestibility Study

Four diets were tested in two experimental periods using cannulated grower-finisher pigs: one wheat control diet and three diets with DDGS. The sole source of energy and AA in the control diet was wheat, whereas in the other three experimental diets, three different types of DDGS (corn, wheat/corn, or wheat) were mixed with wheat (Table 1). Chromic oxide was included as an indigestible marker and diets were fortified to meet or exceed vitamins and mineral requirements [National Research Council (NRC) 1998]. A total of 12 barrows (64.6 ± 6.4 kg; PIC Canada Ltd., Airdrie, AB) were surgically fitted with a T-cannula at the distal ileum and fed two experimental diets each in a controlled change-over design (Li et al. 1994), for a total of 24 observations or six observations per diet.

Each 11-d experimental period consisted of a 6-d acclimation to experimental diets followed by a 3-d collection of

Table 1. Ingredient composition of experimental diets used in the digestibility study

Ingredient (%)	Wheat Control	Distiller's dried grains with solubles		
		Corn	Wheat/corn[z]	Wheat
Wheat	96.3	56.3	56.3	56.3
Distiller's dried grain with solubles				
Corn	–	40.0	–	–
Wheat/corn	–	–	40.0	–
Wheat	–	–	–	40.0
Limestone	1.1	1.1	1.1	1.1
Dicalcium phosphate	0.8	0.8	0.8	0.8
Mineral mix[y]	0.5	0.5	0.5	0.5
Vitamin mix[x]	0.5	0.5	0.5	0.5
Chromic oxide	0.4	0.4	0.4	0.4
Salt	0.4	0.4	0.4	0.4

[z]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.
[y]Provided per kg of diet: Zn, 100 mg as zinc sulphate; Fe, 80 mg as ferrous sulphate; Cu, 50 mg as copper sulphate; Mn, 25 mg as manganous sulphate; I, 0.5 mg as calcium iodate; Se, 100 µg as sodium selenite.
[x]Provided per kg of diet: vitamin A, 8250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 200 µg; vitamin B_{12}, 25 µg.

faeces and urine and then a 2-d collection of ileal digesta. The 12 pigs were housed in individual metabolism pens in one room. The dimensions of the pens were 1.5 (length) × 1.5 (width) × 0.9 m (height), and allowed freedom of movement of pigs during the entire experiment. The flooring of the pen was plastic-coated expanded metal and the siding was sturdy PVC-planking with a transparent plastic window to allow visual contact between pigs in adjacent pens. A single-space feeder and a bowl-drinker were located at the front of each pen. The room was maintained within the thermo-neutral zone of the pigs, with a 14-h light (0700 to 2100)/10-h dark cycle. During the entire experiment, diets were provided in wet-mash form, in a 1:1 water to mash ratio. To avoid orts, daily feed allowance was adjusted to 2.6 × maintenance [2.6 × 110 kcal DE kg^{-1} body weight $(BW)^{0.75}$; NRC 1998] based on average BW at the start of each 11-d experimental period using an estimated diet DE content of 3300 kcal kg^{-1}. Diets were fed in two equal meals at 0800 and 1600; 1.95 and 2.20 kg feed d^{-1} during the first and second period, respectively. Pigs had free access to water throughout the experiment.

During the collections, representative diet samples were collected. Faeces were collected for 3 d twice per day (0800 and 1600) using faeces collection systems (Van Kleef et al. 1994). Urine was quantitatively collected for 3 d during faeces collections for a minimum of two times per day using urine trays and collection bottles. Twenty mL of 12 N HCl was added to the collection bottles prior to each collection to prevent volatilization of urinary N. Of the collected urine, 10% was sub-sampled. Digesta samples were collected in 4% formic acid every 2 h for 10 h d^{-1} during 2 d, using plastic bags affixed to the open T-cannula barrel. Collected faeces, urine and digesta samples were pooled per pig over each collection period and stored with diet samples in a freezer maintained at –20°C.

Exp. 2 – Performance Study

Four diets (one wheat-based control diet and three DDGS-containing diets) were formulated and used in a performance study with grower-finisher pigs (52.0 ± 3.3 kg; PIC Canada Ltd., Airdrie, AB). The main ingredients of the control diet were wheat, peas, and soybean meal. In the other three experimental diets 25% DDGS was included, replacing a portion of wheat, soybean meal and dicalcium phosphate. Diets were formulated, using the digestible energy, AA, and P content determined for each DDGS sample in the digestibility study, to meet or exceed the requirements for AA and other nutrients (NRC 1998), to 3.375 Mcal DE kg^{-1} and 2.50 g standardized ileal digestible lysine $Mcal^{-1}$ DE (Table 2). Other essential AA were formulated as a ratio to lysine (NRC 1998). A total of 100 grower pigs (40 barrows and 60 gilts ensuring identical gender within each group of four pens) were selected based on BW and average daily gain (ADG) since birth, randomized within gender, and housed in one room, with five pigs per pen, in 20 pens. Barrows and gilts were penned separately and each of the four experimental diets was fed to two pens with barrows and three pens with gilts, for a total of five observations per diet. Two pigs from separate pens fed different diets were removed from the experiment due to tail biting and data collected from these pigs were excluded from statistical analyses.

The duration of the study period was 6 wk: a 1-wk adaptation to the room, pen, and pen mates followed by 5-wk feeding of experimental diets. The switch from grower diet to experimental diets was abrupt, i.e., without having a period of mixing the diets together. Pens measured 2.36 × 1.68 m. The flooring of the pen was fully slatted concrete and the siding was sturdy PVC-planking. A single-space feeder was located at the front and a nipple-drinker was located at the back of the pen. The room was maintained within the thermo-neutral zone of the pigs, with a 14-h light (0700 to 2100)/10-h dark cycle. Diets were provided as a dry mash and diets and water were supplied *ad libitum* throughout the experiment.

Pigs were weighed at the initiation of feeding the experimental diets (day 0), and weekly thereafter, (days 7, 14, 21, 28, and 35). Feed disappearance was measured on each weigh day. The data were used to calculate ADG, ADFI, and feed efficiency (G:F).

Table 2. Ingredient composition and calculated energy and lysine content of experimental diets used in the performance study

Ingredient (%)	Wheat Control	Distiller's dried grains with solubles		
		Corn	Wheat/corn[z]	Wheat
Wheat	63.14	41.64	41.18	41.17
Peas	25.00	25.00	25.00	25.00
Distiller's dried grains with solubles				
Corn	–	25.00	–	–
Wheat/corn	–	–	25.00	–
Wheat	–	–	–	25.00
Soybean meal	7.20	4.40	4.40	4.40
Dicalcium phosphate	1.10	0.40	0.40	0.40
Canola oil	0.90	0.70	1.20	1.20
Limestone	0.75	1.00	1.00	1.00
Mineral mix[y]	0.50	0.50	0.50	0.50
Vitamin mix[x]	0.50	0.50	0.50	0.50
Sodium bicarbonate	0.29	0.29	0.29	0.29
L-Lysine-HCl	0.27	0.32	0.33	0.34
Salt	0.20	0.20	0.20	0.20
L-Threonine	0.10	0.05	–	–
DL-Methionine	0.05	–	–	–
Calculated nutrient content (as fed)				
Digestible energy (Mcal kg^{-1})	3.375	3.375	3.375	3.375
SID Lysine (g Mcal^{-1} DE)[w]	2.50	2.50	2.50	2.50

[z]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.
[y]Provided per kg of diet: Zn, 100 mg as zinc sulphate; Fe, 80 mg as ferrous sulphate; Cu, 50 mg as copper sulphate; Mn, 25 mg as manganous sulphate; I, 0.5 mg as calcium iodate; Se, 100 µg as sodium selenite.
[x]Provided per kg of diet: vitamin A, 8250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 200 µg; vitamin B_{12}, 25 µg.
[w]Other essential AA were formulated as a ratio to lysine (NRC 1998)

Chemical Analyses

Faeces and digesta samples were thawed, homogenized, sub-sampled and freeze-dried. Urine was thawed, homogenized, sub-sampled and frozen. Ingredient, feed and freeze-dried faeces and digesta samples were ground through a 1-mm screen.

Chemical analyses were conducted in duplicate. For the digestibility study, the ingredient, feed, faeces and digesta samples were analysed for dry matter (DM) content by drying at 135°C in an airflow type oven for 2 h (method 930.15; AOAC 1990). Feed, faeces and digesta samples were analysed for chromic oxide after ashing at 450°C (Fenton and Fenton 1979) and gross energy using an IKA oxygen bomb calorimeter (model C 5003, IKA GmbH & Co. KG, Staufen, Germany). The calorimeter was operated in dynamic mode and benzoic acid was used as a caloric standard for calibration. Ingredient, feed and faeces samples were analysed for P according to the method described by Zasoski and Burau (1977) and urine was analysed for P using the molybdo-phosphate method (method 964.06; AOAC 1990). Feed, faeces and urine were analyzed for N by combustion (method 968.06; AOAC 1990) using a Leco protein/N analyzer (model FP–528, Leco Co., St. Joseph, MI). Ingredient, feed and digesta samples were analysed for AA (method 982.30E; AOAC 1990) at the University of Missouri, Columbia, MO. In addition, the wheat sample used in the digestibility study and the DDGS samples were analyzed for crude protein (CP; method 988.05; AOAC 1990), crude fat (method 954.02; AOAC 1990), ash (method 942.05; AOAC 1990), crude fibre (method 962.09; AOAC 1990), acid detergent fibre (ADF) and neutral detergent fibre (NDF) using an Ankom fiber analyzer (model ANKOM^{200}, Ankom Technology, Fairport, NY) using sodium sulphite and α-amylase in the NDF procedure, and non-protein N (NPN; Licitra et al. 1996). The four ingredient samples were analyzed for intact phytate, i.e., inositol hexaphosphate (IP6), and lower IP (IP2 to IP5) by high performance liquid chromatography (Newkirk and Classen 1998) and soluble and insoluble non-starch polysaccharides (NSP) and constituent sugars by gas-liquid chromatography (Englyst and Hudson 1987).

Calculations and Statistical Analyses

Apparent ileal and total tract digestibility of nutrients and nutrient excretion were calculated for the four diets using the indicator method (Adeola 2001). Coefficients for the wheat ingredient were assumed equal to wheat control diet for energy and AA, whereas the digestibility coefficients for P were corrected for the digestible P provided by dicalcium phosphate. The digestibility coefficients and digestible nutrient content of the three DDGS samples were separated from wheat using the difference method (Fan and Sauer 1995). Standardized ileal digestibility (SID) of AA was calculated from apparent ileal digestibility (AID) coefficients using the method of Yin et al. (2002), based on the mean endogenous AA composition of basal endogenous protein (Jansman et al. 2002). The digestible nutrient content was calculated using total nutrient content multiplied by the digestibility coefficients.

Pig was considered the experimental unit for the digestibility study and pen for the performance study. Digestibility variables were analysed using the general linear models procedure of SAS (`SAS Institute, Inc. 1996). Means were reported as least-square means [± pooled standard error of the mean (SEM)] and were separated using the probability of difference; $P < 0.05$ was considered significant to test the hypotheses. If pertinent, trends ($0.05 < P < 0.10$) were reported and $P > 0.10$ was considered non-significant. Performance variables were analyzed by analysis of variance using the MIXED procedure of SAS (Wang and Goonewardene 2004) using a statistical model with the following factors: diet, gender and diet × gender, and initial BW as a covariate. The wheat was compared to the three DDGS samples combined using a contrast.

RESULTS

Chemical Characteristics

Overall for the measured characteristics, the content was lower for the wheat sample than the three DDGS samples, except for phytate. The CP content was highest for wheat DDGS (Table 3). The NPN content of wheat/corn DDGS and wheat DDGS was 6%-units higher than for corn DDGS. The crude fat content was 10%-units higher for corn DDGS than wheat DDGS. The ash, ADF, NDF, and crude fibre contents were similar among the DDGS samples, and were all higher than in wheat.

Similar to CP content, the total and indispensable AA contents were highest for wheat DDGS followed by wheat/corn DDGS and corn DDGS, with the exception of leucine and lysine (Table 3). The leucine and lysine content was highest for corn DDGS. With the exception of lysine, the AA content in wheat DDGS doubled that of wheat.

Among the DDGS samples, wheat DDGS had the highest total P content and corn DDGS had the highest intact phytate (IP6) content (Table 4). Wheat did not contain any of the lower forms of phytate (IP2, IP3, IP4 and IP5). In addition to phytate, wheat DDGS contained all lower inositol phosphate forms of phytate; corn DDGS and wheat/corn DDGS did not contain IP2.

Among the DDGS, wheat DDGS had the highest soluble and total NSP content, but corn DDGS had the highest insoluble NSP content (Table 4). The constituent sugars were similar among the DDGS, with wheat DDGS having the highest soluble xylose, arabinose and glucose content. Concentrations of mannose and galactose were, overall, low.

Nutrient Digestibility and Content

The apparent ileal and total-tract digestibility of energy did not differ among DDGS samples ($P > 0.10$; Table 5); however, ileal and total-tract energy digestibility was 8 and 9%, respectively, higher for the wheat than for the DDGS samples ($P < 0.05$). The total-tract digestibility of P did not differ among the DDGS samples ($P > 0.10$), but was 40%-units higher for DDGS than the wheat ($P < 0.05$).

The AID of indispensable and total AA (Table 5) and the SID of the indispensable AA (Table 6) were similar among DDGS samples ($P > 0.10$), with the exception of threonine. The AID of threonine was similar for wheat/corn DDGS and wheat DDGS ($P > 0.10$), but lower for corn DDGS ($P < 0.05$) and the SID of threonine was lower for corn DDGS than for wheat/corn DDGS ($P < 0.05$). However, AID and SID of the indispensable and total AA were higher for wheat than DDGS ($P < 0.05$), except for the AID of arginine, leucine, methionine, threonine, tryptophan, and valine ($P > 0.10$).

Among DDGS samples, the contents of standardized ileal digestible AA were highest for wheat DDGS followed by wheat/corn DDGS and corn DDGS ($P < 0.05$; Table 7), except for leucine, lysine, methionine, and threonine. Specifically, ileal digestible leucine contents were lowest for wheat DDGS and highest for corn DDGS ($P < 0.05$). The ileal digestible lysine, methionine and threonine contents were similar for wheat DDGS and wheat/corn DDGS ($P > 0.10$); however, corn DDGS had the highest contents for lysine and the lowest contents for methionine and threonine ($P < 0.05$). Overall, ileal digestible contents of indispensable AA were lower for the wheat than DDGS ($P < 0.05$).

The apparent ileal DE content did not differ among DDGS samples ($P > 0.10$; Table 7), but total tract DE content was higher for corn DDGS than wheat/corn DDGS and wheat DDGS ($P < 0.05$). Total tract DE content tended to be higher for wheat/corn DDGS and wheat DDGS than wheat ($P = 0.06$), and ileal and total tract DE contents were lower for wheat than the DDGS samples combined ($P < 0.05$). The digestible P content was similar ($P > 0.10$) among DDGS samples and higher for DDGS than wheat ($P < 0.05$).

Nutrient Excretion

The DM intake was similar among pigs fed wheat control and DDGS diets ($P > 0.10$; Table 8). Pigs fed wheat/corn DDGS and wheat DDGS had a higher daily N and P intake than pigs fed corn DDGS ($P < 0.05$). The N and P intake was lower for pigs fed wheat than pigs fed DDGS ($P < 0.05$).

The DM excretion on daily basis and as a percentage of intake was similar among pigs fed DDGS diets ($P > 0.10$; Table 8). The DM excretion was higher for pigs fed DDGS than the wheat control diet ($P < 0.05$).

Pigs fed wheat/corn DDGS excreted the highest amount of faecal N on a daily basis, followed by pigs fed the wheat DDGS and corn DDGS ($P < 0.05$; Table 8). Pigs fed DDGS had a higher faecal N excretion than pigs fed the wheat control ($P < 0.05$). Similarly, feeding DDGS increased urinary N excretion compared to the wheat control ($P < 0.05$). Total N excretion was higher for pigs fed wheat/corn DDGS and wheat DDGS than pigs fed corn DDGS ($P < 0.05$). Total N excretion did not differ between pigs fed the wheat control and corn DDGS ($P > 0.10$). Daily N retention was similar among pigs fed DDGS ($P > 0.10$), but was lower for pigs fed the wheat control than for pigs fed DDGS ($P < 0.05$).

Daily excretion of faecal, urinary and total P and P retention were similar among pigs fed DDGS ($P > 0.10$; Table 8), and was lower for the wheat control than DDGS ($P < 0.05$). Percentage of N and P retained did not differ among the four experimental diets ($P > 0.10$).

Growth Performance

For the performance trial, final BW, ADG and ADFI did not differ among pigs fed diets containing DDGS for any of the

Table 3. Chemical characteristics of wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles (% DM)

		Distiller's dried grains with solubles		
Variable	Wheat	Corn	Wheat/corn[z]	Wheat
Moisture	11.8	11.8	8.0	8.1
Crude protein	19.8	30.3	42.4	44.5
Non-protein nitrogen	4.6	5.4	12.4	10.2
Crude fat	1.8	12.8	4.7	2.9
Ash	2.1	4.8	5.0	5.3
Acid detergent fibre	2.7	14.6	19.5	21.1
Neutral detergent fibre	9.4	31.2	30.6	30.3
Crude fibre	2.4	7.0	7.8	7.6
Amino acid				
Arginine	0.91	1.33	1.64	1.77
Cysteine	0.48	0.70	0.89	0.96
Histidine	0.46	0.82	0.95	0.99
Isoleucine	0.68	1.14	1.50	1.59
Leucine	1.31	3.52	3.13	3.01
Lysine	0.52	0.83	0.72	0.72
Methionine	0.32	0.61	0.67	0.69
Phenylalanine	0.96	1.51	1.98	2.16
Threonine	0.54	1.09	1.22	1.28
Tryptophan	0.23	0.23	0.37	0.44
Valine	0.84	1.53	1.83	1.91
Total	19.48	28.32	37.25	40.21

Table 4. Phosphorus, inositol phosphates and non-starch polysaccharide (NSP) including constituent sugar profile of wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles (% DM)

		Distiller's dried grains with solubles		
Variable	Wheat	Corn	Wheat/corn[z]	Wheat
Phosphorus	0.40	0.86	1.02	1.10
Inositol phosphates				
Inositol diphosphate (IP2)	0.00	0.00	0.00	0.08
Inositol triphosphate (IP3)	0.00	0.09	0.09	0.09
Inositol quadraphosphate (IP4)	0.00	0.19	0.18	0.28
Inositol pentaphosphate (IP5)	0.00	0.45	0.33	0.64
Phytate (IP6)	1.39	0.92	0.62	0.81
Total NSP				
Soluble	2.15	1.39	5.35	7.76
Insoluble	7.57	17.85	16.56	15.13
Total	9.72	19.24	21.91	22.89
Xylose				
Soluble	1.03	0.29	2.53	3.08
Insoluble	2.39	5.86	5.58	5.00
Total	3.42	6.15	8.11	8.08
Arabinose				
Soluble	0.68	0.21	1.22	1.58
Insoluble	1.64	4.06	3.51	3.29
Total	2.32	4.27	4.73	4.87
Mannose				
Soluble	0.04	0.29	0.43	0.34
Insoluble	0.10	0.66	0.59	0.58
Total	0.14	0.95	1.02	0.92
Galactose				
Soluble	0.23	0.07	0.27	0.51
Insoluble	0.40	1.37	1.04	0.82
Total	0.63	1.44	1.31	1.33
Glucose				
Soluble	0.07	0.46	0.73	1.09
Insoluble	3.03	5.79	5.78	5.38
Total	3.10	6.25	6.51	6.47

[z]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

Table 5. Apparent ileal digestibility (%) of energy and amino acids and total tract digestibility (%) of energy and P in wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles measured in grower-finisher pigs

		Distiller's dried grains with solubles			
Variable[z]	Wheat	Corn	Wheat/corn[y]	Wheat	Pooled SEM
Ileal digestibility (%)					
Energy[x]	71.8	67.3	66.5	65.6	1.63
Amino acid					
Arginine	87.9	85.7	85.2	85.8	1.01
Cysteine[x]	84.1*a*	77.4*b*	78.2*b*	77.0*b*	1.22
Histidine[x]	87.6*a*	81.5*b*	80.8*b*	80.9*b*	1.08
Isoleucine[x]	83.5*a*	78.0*b*	79.4*b*	79.0*b*	1.07
Leucine	85.2	84.4	83.8	82.9	0.72
Lysine[x]	70.6*a*	61.8*b*	62.8*b*	58.6*b*	2.07
Methionine	85.0	84.2	84.2	82.6	0.91
Phenylalanine[x]	87.9*a*	84.0*b*	86.2*ab*	86.4*ab*	0.77
Threonine	73.7*a*	69.4*b*	74.4*a*	72.8*a*	1.04
Tryptophan	85.1	81.7	81.4	82.5	1.79
Valine	86.0	83.0	84.9	84.6	0.81
Total[x]	85.5*a*	79.9*b*	81.5*b*	81.2*b*	0.92
Total tract digestibility (%)					
Energy[x]	84.8*a*	78.7*b*	76.8*b*	77.4*b*	1.39
Phosphorus[x]	14.8*b*	55.5*a*	54.7*a*	53.0*a*	4.15

[z]Means are least-square means for the four feedstuffs.
[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.
[x]Wheat differs from the three DDGS ($P < 0.05$).
a–b Within a row, means without a common letter differ ($P < 0.05$).

Table 6. Standardized ileal digestibility (%) of amino acids in wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles measured in grower-finisher pigs

		Distiller's dried grains with solubles			
Amino acid[z]	Wheat	Corn	Wheat/corn[y]	Wheat	Pooled SEM
Arginine[x]	92.2*a*	88.6*b*	87.6*b*	88.0*b*	1.01
Cysteine[x]	88.4*a*	80.4*b*	80.6*b*	79.2*b*	1.22
Histidine[x]	91.7*a*	83.8*b*	82.8*b*	82.8*b*	1.07
Isoleucine[x]	89.1*a*	81.3*b*	81.9*b*	81.4*b*	1.06
Leucine[x]	88.9*a*	85.8*b*	85.3*b*	84.5*b*	0.71
Lysine[x]	78.3*a*	66.6*b*	68.4*b*	64.1*b*	2.08
Methionine[x]	88.4*a*	86.0*ab*	85.9*ab*	84.2*b*	0.91
Phenylalanine[x]	91.4*a*	86.2*b*	88.0*b*	88.0*b*	0.77
Threonine[x]	85.0*a*	75.0*c*	79.4*b*	77.5*bc*	1.04
Tryptophan[x]	91.2	87.8	85.2	85.7	1.79
Valine[x]	92.4*a*	86.5*b*	87.8*b*	87.4*b*	0.81

[z]Means are least-square means for the four feedstuffs.
[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.
[x]Wheat differs from the three DDGS ($P < 0.05$).
a–c Within a row, means without a common letter differ ($P < 0.05$).

weeks or the entire experimental period ($P > 0.10$; Table 9). Final BW, ADG and ADFI were higher for pigs fed the wheat control than for pigs fed DDGS ($P < 0.05$). However, DDGS did not affect feed efficiency of pigs ($P > 0.10$).

DISCUSSION

In the present study, the chemical and nutritional properties varied among samples of DDGS, similar to previous studies (e.g., Carpenter 1970; Cromwell and Stahly 1986; Cromwell et al. 1993; Stein et al. 2006). Generally, nutrient variability of DDGS cannot be entirely avoided, because DDGS is a by-product of a process primarily aimed at the production of ethanol. In the present study, the variation was large, because DDGS was produced from two feedstocks (wheat and corn) at two ethanol plants. Overall, factors including the type of cereal grain used for fermentation, method of fermentation (batch or continuous), completeness or duration of the fermentation process, drying temperature and duration, and the amount of dried solubles blended with distiller's dried grains can affect the chemical, physical and nutritional characteristics of DDGS (Carpenter 1970; Olentine 1986; Spiehs et al. 2002). The nutrient composition of DDGS should still reflect the nutrient content of original cereal grain, with a higher concentration of remaining nutrients following starch removal (Sosulski and Tarasoff 1997; Weigel et al. 1997; Mustafa et al. 1999). Indeed, the nutri-

Table 7. Standardized ileal digestible amino acid content (% DM), ileal and total tract digestible energy (kcal kg^{-1} DM) and total tract digestible P (% DM) contents in wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles measured in grower-finisher pigs

		Distiller's dried grains with solubles			
Variable[z]	Wheat	Corn	Wheat/corn[y]	Wheat	Pooled SEM
Amino acid					
Arginine[x]	0.84*d*	1.18*c*	1.44*b*	1.56*a*	0.02
Cysteine[x]	0.43*d*	0.56*c*	0.72*b*	0.76*a*	0.01
Histidine[x]	0.42*d*	0.69*c*	0.79*b*	0.82*a*	0.01
Isoleucine[x]	0.61*d*	0.93*c*	1.23*b*	1.30*a*	0.01
Leucine[x]	1.17*d*	3.02*a*	2.67*b*	2.54*c*	0.02
Lysine[x]	0.41*c*	0.55*a*	0.49*b*	0.46*b*	0.02
Methionine[x]	0.28*c*	0.52*b*	0.58*a*	0.58*a*	0.01
Phenylalanine[x]	0.88*d*	1.30*c*	1.74*b*	1.90*a*	0.01
Threonine[x]	0.46*c*	0.82*b*	0.97*a*	0.99*a*	0.01
Tryptophan[x]	0.21*c*	0.20*c*	0.32*b*	0.38*a*	0.01
Valine[x]	0.78*d*	1.33*c*	1.61*b*	1.67*a*	0.01
Digestible energy					
Ileal[x]	3224*b*	3671*a*	3495*ab*	3406*ab*	82.1
Total tract[x]	3807*b*	4292*a*	4038*b*	4019*b*	73.4
Phosphorus[x]	0.06*b*	0.48*a*	0.56*a*	0.59*a*	0.04

[z]Means are least-square means for the four feedstuffs.
[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.
[x]Wheat differs from the three DDGS ($P < 0.05$).
a–d Within a row, means without a common letter differ ($P < 0.05$).

Table 8. Intake, excretion and retention of dry matter, N and P of grower-finisher pigs fed a wheat-control diet or diets containing 40% corn, wheat/corn, or wheat distiller's dried grains with solubles (DM basis)

		Distiller's dried grains with solubles			
Variable[z]	Wheat control	Corn	Wheat/corn[y]	Wheat	Pooled SEM
DM intake (g d^{-1})	1780	1838	1885	1796	35.2
DM excretion (g d^{-1})[x]	237*b*	381*a*	391*a*	360*a*	12.2
DM excretion (%)[x]	13.4*b*	20.7*a*	20.8*a*	20.1*a*	0.62
N intake (g d^{-1})[x]	55.4*c*	69.5*b*	83.7*a*	86.6*a*	1.53
N excretion (g d^{-1})					
Faeces[x]	6.1*d*	11.3*c*	14.5*a*	13.0*b*	0.48
Urine[x]	29.7*c*	32.7*bc*	40.7*ab*	44.7*a*	3.04
Total[x]	35.7*b*	44.1*b*	55.2*a*	57.7*a*	2.94
N retention (g d^{-1})[x]	19.7	25.4	28.6	28.9	2.75
N retention (%)	35.6	36.4	33.9	33.2	3.69
P intake (g d^{-1})[x]	11.4*c*	15.2*b*	16.6*a*	16.6*a*	0.29
P excretion (g d^{-1})					
Faeces[x]	6.9*b*	8.5*a*	8.4*a*	8.4*a*	0.29
Urine[x]	1.1*b*	2.0*a*	2.7*a*	2.7*a*	0.20
Total[x]	8.0*b*	10.5*a*	11.0*a*	11.1*a*	0.33
P retention (g d^{-1})[x]	3.4*b*	4.6*a*	5.6*a*	5.6*a*	0.27
P retention (%)	29.8	30.6	33.5	33.5	1.73

[z]Means are least-square means for the four diets.
[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.
[x]Wheat differs from the three DDGS ($P < 0.05$).
a–d Within a row, means without a common letter differ ($P < 0.05$).

ent content was higher for the wheat DDGS sample than for the wheat sample used in the present study.

One of the main observations of the present study was a lower total content of the first-limiting AA, lysine, in wheat DDGS compared with corn DDGS, despite a markedly higher CP and total AA content in wheat DDGS than corn DDGS. This low total lysine content and the high NPN content indicates that some of the lysine and AA were damaged during the fermentation and/or drying processes of the wheat DDGS and wheat/corn DDGS. These two DDGS samples had a dark colour with slightly burnt odour, suggesting that the DDGS was overheated during the drying process (Cromwell et al. 1993; Fastinger and Mahan 2006). The comparatively low moisture content of wheat-based DDGS also indicated excessive drying. In contrast to wheat DDGS, the corn DDGS was lighter in colour with sweet and

Table 9. Growth performance of grower-finisher pigs fed a wheat-control diet or diets containing 25% corn, wheat/corn, or wheat distiller's dried grains with solubles

Variable[z]	Wheat control	Distiller's dried grains with solubles Corn	Wheat/corn[y]	Wheat	Pooled SEM
Body weight (kg)					
Day 0	51.70	51.88	53.39	51.17	0.44
Day 7	60.19	59.58	59.04	59.45	0.44
Day 14	67.01	65.99	65.83	65.78	0.44
Day 21	74.33	72.30	72.22	72.33	0.44
Day 28	81.31*a*	78.89*ab*	78.77*b*	78.89*ab*	0.44
Day 35[x]	88.06*a*	85.82*ab*	85.39*b*	85.70*ab*	0.44
ADG (kg d^{-1})					
Day 0 to 7	1.136	1.056	1.011	1.024	0.03
Day 8 to 14	0.982	0.922	0.959	0.920	0.03
Day 15 to 21	1.056	0.906	0.899	0.950	0.03
Day 22 to 28	1.004	0.950	0.923	0.948	0.03
Day 29 to 35	0.972	0.996	0.933	0.990	0.03
Day 0 to 35[x]	1.030*a*	0.966*ab*	0.945*b*	0.967*ab*	0.03
ADFI (kg d^{-1})					
Day 0 to 7	2.455	2.294	2.212	2.309	0.05
Day 8 to 14	2.723	2.608	2.558	2.475	0.05
Day 15 to 21	2.823	2.618	2.676	2.687	0.05
Day 22 to 28	2.943*a*	2.802*ab*	2.664*b*	2.863*ab*	0.05
Day 29 to 35	2.973	2.880	2.928	2.925	0.05
Day 0 to 35[x]	2.784*a*	2.640*b*	2.607*b*	2.651*b*	0.05
Feed efficiency					
Day 0 to 7	0.462	0.460	0.358	0.445	0.01
Day 8 to 14	0.362	0.355	0.375	0.377	0.01
Day 15 to 21	0.376	0.347	0.335	0.355	0.01
Day 22 to 28	0.340	0.341	0.360	0.332	0.01
Day 29 to 35	0.328	0.349	0.320	0.342	0.01
Day 0 to 35	0.373	0.371	0.370	0.370	0.01

[z]Means are least-square means for the four diets.
[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.
[x]Wheat differs from the three DDGS ($P < 0.05$).
a–b Within a row, means without a common letter differ ($P < 0.05$).

slightly fermented odour suggesting a supply of appropriate heat during drying. Following overheating, lysine forms complexes with carbonyl groups, the Maillard reaction, which is associated with a colour change. The Maillard reaction is stimulated by heat in the presence of moisture, the exact conditions present in the drying process and heat should thus be reduced to prevent lysine degradation.

Apparent ileal or total-tract digestibility of energy and AID or SID of indispensable AA were lower for DDGS compared with the wheat sample. Soluble and insoluble NSP were concentrated with other nutrients in DDGS during fermentation (Mustafa et al. 1999) and likely contributed to the lower digestibility of DM, energy and AA in DDGS in the present study (Zijlstra et al. 1999; de Lange 2000; Jondreville et al. 2001). The measured digestibilities for AA in the present study compared with the range of coefficients measured recently for corn DDGS (Fastinger et al. 2006; Stein et al. 2006) and wheat DDGS (Nyachoti et al. 2005). Based on fibre content of DDGS, plausible factors contributing to low apparent AA digestibility in DDGS could be decreased enzymatic breakdown of dietary protein, thereby reduced absorption and increased undigested protein (AA) in digesta, or increased endogenous AA losses (Jondreville et al. 2001).

Undigested P is excreted in faeces, and may impact the environment negatively (Cromwell et al. 1993; NRC 1998). Interestingly, P digestibility in DDGS was higher compared with wheat in the present study. Approximately 60 to 70% of the total P in a cereal-based diet is bound to phytate, and this phytate-P is not digested by swine (Baker 1991). The high P digestibility in DDGS was consistent with previous research [Singsen et al. (1972) as referenced by Cromwell (1979)] indicating that P availability is enhanced in DDGS due to phytate-P hydrolysis. In the present study, the breakdown of phytate during fermentation was validated by the presence of less complex forms of phytate and the reduced intact phytate (IP6) content in wheat DDGS compared to the wheat sample. A higher P digestibility in DDGS compared with cereals suggests that feeding DDGS might improve P management in swine diets and manure, in contrast to N.

Digestible nutrient content information is important for diet formulation. Despite the highest energy digestibility, apparent ileal and total-tract DE content remained lower in the wheat sample than in the wheat DDGS, contrasting previous research indicating that wheat had a higher DE content than wheat DDGS (Nyachoti et al. 2005). The higher fat content in corn DDGS compared with wheat DDGS is associated with a higher gross energy content and therefore a higher DE content in corn DDGS than wheat DDGS (Spiehs et al. 2002). The achieved DE content in DDGS indicates that the DE reduction caused by a high NSP content can be overcome with a high fat content. The substantially higher digestible P content in DDGS is due to a higher P content and digestibility. Even though the ileal digestibility values of most of the indispensable AA were higher in the wheat sample than DDGS, the digestible AA contents in DDGS were higher due to higher AA content in DDGS samples.

In the present study, DM excretion was higher for pigs fed DDGS-containing diets than for pigs fed the wheat-control diet, suggesting that feeding DDGS will increase manure volume. The increased DM excretion might be due to the high NSP content of DDGS, because addition of a fibre source to the diet elevates faecal DM excretion in pigs (Cherbut et al. 1988), especially fermentable NSP (Canh et al. 1998).

The higher N intake of pigs fed DDGS-containing diets compared with wheat-control diets was due to a higher CP content in DDGS, and was directly related to an increased N excretion in faeces and urine, especially with wheat DDGS. Almost 25% of the CP was NPN in wheat DDGS, and is partially responsible for the increased N excretion. The increased urinary N excretion indicates increased AA catabolism, suggesting an imbalanced AA profile or a limitation in one or more limiting AA in DDGS (de Lange 2004). Interestingly, N retention as a percentage of N intake was not affected by DDGS in the diet, indicating that CP and AA contained in DDGS can be utilized by the pig.

Intake, excretion and retention of P were affected by DDGS. The higher P content in DDGS compared with wheat increased P intake of pigs fed diets with DDGS, especially for wheat/corn DDGS and wheat DDGS. As a consequence of increased P intake with DDGS, increased amounts of P appeared in faeces and urine (Cromwell et al. 1993; Ekpe et al. 2002). The increased P digestibility in DDGS could not entirely overcome the increased content of digestible P in DDGS. The amount of digested P surpassed the P requirement of pigs fed DDGS in the present study, resulting in excess urinary P excretion (Ekpe et al. 2002). Despite the increased excretion, daily P retention was higher for pigs fed DDGS-containing diets than pigs fed the wheat control diet. Similar to N retention, P retention as a percentage of P intake was not affected by dietary DDGS, indicating once more that P in DDGS was utilized to a large extent by pigs in the present study, and contributed directly to meeting the digestible P requirement (Jongbloed et al. 1999).

In the present study, inclusion of DDGS reduced growth performance of pigs without affecting feed efficiency. The DDGS contains a higher digestible energy and AA content than wheat, but following pre-characterization and incorporation of the digestible nutrient content information in diet formulation, DDGS caused a reduction in voluntary feed intake, ADG and final BW. Reasons for the reduced feed intake remain unclear; dietary inclusion of DDGS might negatively affect palatability (Whitney and Shurson 2004), or the high NSP content in DDGS might play a role, because a high dietary fibre content reduces feed intake in pigs (Noblet and Le-Goff 2001).

The increased fermentation and increased CP content in the diet limiting in lysine is likely caused extra heat increment as a result of catabolism of excess AA (Henry et al. 1992). Indeed, feeding DDGS to swine increased N excretion, and thereby increased the requirement of energy for N excretion, leaving less energy available to support growth (Spiehs et al. 2002). In addition, the daily intake of digestible lysine was lower for pigs fed diets with DDGS than fed the wheat control diet, mainly due to a lower feed intake, because the diets were formulated to an equal digestible lysine content. The reduced digestible lysine intake for DDGS, together with reduced lysine availability in DDGS may have constrained protein accretion of pigs fed diets with DDGS, because lysine intake below requirement will suppress growth performance of grower-finisher pigs (Friesen et al. 1994).

The results of the present study indicate that wheat DDGS is a by-product with a nutritional value for swine that is higher than wheat. Wheat DDGS has a lower nutritional value than corn DDGS, and the AA damaged by processing, a higher xylose content and lower crude fat content might together be constraints to the nutritional value of wheat DDGS for pigs. Dietary DDGS might increase N and P excretion in pigs. Finally, the nutritional value of wheat DDGS can be enhanced by improving its digestible AA content with improved fermentation and drying processes and reducing the impact of NSP with supplementary enzymes or other technologies.

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