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Energy and nutrient digestibilities in wheat dried distillers' grains with solubles fed to growing pigs

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Abstract: The aim of this study was to characterize the nutritional profile and to determine the digestibilities of nutrients in wheat-based dried distillers' grains with solubles (DDGS) fed to growing pigs. Six ileal cannulated barrows individually housed in metabolism crates were fed experimental diets which consisted of a basal wheat-based diet or the basal diet with wheat replaced by 400 g kg^{-1} mixed wheat or winter wheat DDGS in a replicated 3 × 3 Latin square design. Ileal digesta and fecal samples were collected for determining apparent ileal (AID) and apparent total tract digestibilities (ATTD), respectively. The contents of proximate components and amino acids in DDGS were about three times higher than in wheat. The AID and ATTD of dry matter, nitrogen and energy were lower ($P < 0.05$) in DDGS compared with wheat. The DDGS samples had lower ($P < 0.05$) AID of amino acids compared with wheat; average values for lysine, threonine and isoleucine in DDGS were 43.8, 62.9 and 68.0%, respectively. The ileal and fecal digestible energy content in DDGS averaged 9.7 ± 1.18 and 13.5 ± 0.61 MJ kg^{-1}, respectively. Respective values for wheat were 13.3 ± 0.52 and 14.6 ± 0.22 MJ kg^{-1} and both were higher ($P < 0.05$) than in DDGS.

Keywords: digestibility; dried distiller's grains with solubles; energy; nutrients; pigs; wheat

INTRODUCTION

There is a growing interest in western Canada in increasing the production of ethanol, using wheat as the base cereal, to meet the demands of legislation requiring the use of ethanol-blended gasoline. The process of ethanol production uses a co-product, dried distillers' grains with solubles (DDGS), that has potential as an ingredient for livestock feed. In North America, corn has been used as the main cereal grain in ethanol production and the resulting DDGS have been extensively evaluated as a feedstuff for swine.[1–4]

There is a paucity of information on the nutritive value of wheat-based DDGS for swine. Boila and Ingalls[5] reported that wheat DDGS contained high crude protein and amino acid contents; however the bioavailability of these and other nutrients for pigs has not been adequately assessed. In a recent study, Widyaratne *et al*[6] reported that wheat DDGS contain 0.30 and 0.88% ileal digestible lysine and threonine, respectively. The digestible energy content of the DDGS in that study was estimated at 13.95 MJ kg^{-1}. Thus, these studies suggest that wheat-based DDGS has potential as a feedstuff for pigs. Nevertheless more research must be done to better utilize this material in commercial swine feed production. Therefore the objective of the current study was to characterize the chemical composition of wheat-based DDGS and to determine the digestibilities of energy, nitrogen, phosphorus, calcium and amino acids in wheat DDGS obtained from an ethanol plant in Manitoba.

MATERIALS AND METHODS

Ingredient samples

The DDGS evaluated in the present study were obtained from the Husky Mohawk ethanol plant at Minnedosa, Manitoba, Canada. All samples were taken from different fermentation batches using wheat as the cereal base. The initial four samples, designated as wheat/corn DDGS, wheat DDGS 1, wheat DDGS 2 and wheat DDGS 3, were obtained in November 2002 and evaluated for proximate composition. In addition, wheat DDGS 1 and 2 samples were evaluated for amino acid composition (Table 1). The DDGS samples used in the animal trial were obtained in May 2003. A mixture of wheat or winter wheat was used in producing the two samples evaluated in the digestibility study. The wheat used in the basal diet was obtained from a local feed supplier.

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Table 1. Chemical composition of dried distillers' grains with solubles (g kg^{-1}, air dry basis)[a]

Item	Wheat/corn DDGS	Wheat DDGS 1	Wheat DDGS 2[b]	Wheat DDGS 3[b]	SD[c]
Dry matter	948.4	927.4	937.7	928.6	5.13
Moisture	51.6	72.7	62.3	71.4	5.13
Gross energy (MJ kg^{-1})	20.5	19.9	19.9	20.0	0.04
Nitrogen	56.8	52.6	59.1	57.9	0.02
Ether extract	44.0	37.8	33.1	32.2	0.43
ADF	189.2	215.5	179.7	183.0	8.75
NDF	375.5	341.7	337.4	332.8	7.00
Ash	46.8	47.1	48.8	49.0	0.83
Total phosphorus	11.2	11.3	11.4	11.8	0.45

[a] Values are mean of triplicate analyses. The DDGS samples were from the same ethanol plant but from different fermentation batches.
[b] Amino acid composition (g kg^{-1}, air dry basis) of wheat DDGS1 and 2, respectively, was: arginine, 9.11 and 13.25; histidine, 6.58 and 6.66; isoleucine, 8.94 and 9.94; leucine, 26.11 and 22.33; lysine, 4.39 and 6.18; methionine, 3.46 and 3.91; phenylalanine, 13.09 and 17.01; threonine, 9.74 and 10.74; tryptophan, 2.63 and 3.62; valine, 11.39 and 12.38; alanine, 14.21 and 11.84; aspartic acid, 16.97 and 17.71; glutamic acid, 71.32 and 92.57; glycine, 12.49 and 14.47; proline, 32.57 and 38.57; serine, 14.27 and 17.67; tyrosine, 10.78 and 12.47.
[c] SD = pooled standard deviation ($n = 4$).

Animals, housing and diets

Six Cotswold barrows with an average initial body weight of 29.8 ± 1.0 kg (mean $\pm$ SD) were obtained from the University of Manitoba Glenlea Swine Research farm for use in the present study. Pigs were housed in individual adjustable metabolism crates (1.18×1.46 m) with smooth, transparent plastic sides and plastic-covered woven metal flooring in a temperature-controlled ($20-22\,^{\circ}$C) room. After a 7-day adaptation period, pigs were surgically fitted with a simple T-cannula at the terminal ileum following the procedures described by Sauer *et al.*[7] After surgery, the pigs were immediately returned to their metabolism cages and allowed a 14-day recovery period. During this period they were fed twice daily with increasing amounts of a corn and soybean meal-based pig starter diet and had unlimited access to water.

The experimental diets used in the digestibility experiment consisted of a basal diet and two DDGS-containing diets. The basal diet consisted of 971 g kg^{-1} wheat as the only source of energy and protein, whereas the DDGS diets contained the basal diet with 400 g kg^{-1} of mixed wheat or winter wheat DDGS in place of wheat. All diets were supplemented with minerals and vitamins to meet or exceed National Research Council (NRC)[2] nutrient specifications for growing pigs. Chromic oxide (4 g kg^{-1}) was included in all diets as an indigestible marker. The use of animals in the present study was reviewed and approved by the Animal Care Committee of the University of Manitoba (protocol no. F01-003/1/2), and the pigs were cared for according to the guidelines of the Canadian Council on Animal Care.[8]

Feeding and digesta and fecal collection procedures

After recovering from surgery, the pigs were randomly divided into two groups of three pigs each and within groups assigned to the experimental diets in a 3×3 Latin square design to give six observations per diet. Daily feed allowance was equivalent to 4% of body weight at the beginning of each experimental period. Pigs were offered equal amounts of the experimental diet twice daily at 08:00 and 20:00 h as a wet mash with a water-to-feed ratio of 2:1. Additional drinking water was available from low-pressure drinking nipples. Feed refusals and spillage were recorded and used to determine actual dry matter intake (DMI).

Each experimental period lasted 8 days. During each experimental period, ileal digesta was collected continuously for a total of 24 h on days 5 and 6 to determine apparent ileal digestibilities (AID). On days 7 and 8, fecal samples were collected to determine apparent total tract digestibilities (ATTD). Digesta were collected into transparent plastic bags attached to the barrel of the T-cannulas with hose clamps. Collection bags contained 10 mL formic acid (4.6 g l^{-1}) to minimize bacterial activity. Bags were changed every 1–2 h and the collected digesta along with fecal samples in sealed plastic bags were immediately frozen at $-20\,^{\circ}$C until further processing.

Sample preparation and chemical analysis

Digesta and fecal samples were pooled per pig per period, freeze-dried, and along with diet and DDGS and wheat samples, finely ground to pass through a 1 mm screen prior to chemical analyses. The proximate composition of each of the four DDGS samples evaluated initially was done in triplicate. All other analyses were performed in duplicate. Dry matter, ash and ether extract were determined using established methods of analysis.[9] Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined according to the method of Goering and Van Soest.[10] Nitrogen content was determined using a Leco NS 2000 Nitrogen Analyzer (LECO Corporation, St Joseph, MI, USA). Gross energy was measured using a Parr adiabatic oxygen bomb calorimeter (Parr Instrument Co., Moline, IL, USA) that had been calibrated. For amino acid analysis, a 100 mg sample was weighed for acid hydrolysis according to the AOAC[9] and as modified by Mills *et al.*[11] Briefly, samples were digested in 4 mL of 6 mol L^{-1} HCl *in vacuo* for 24 h at 110 °C, followed by neutralization with 4 mL NaOH (250 g l^{-1}) and allowed to cool to room temperature. The mixture was then made up to 50 mL volume with sodium citrate buffer (19.6 g l^{-1}; pH 2.2) and analyzed using a LKB 4151 Alpha analyzer (LKB Biochrom, Cambridge, UK). Methionine, cystine and tryptophan were not determined. Phytate content in the ingredients, diet, digesta and fecal samples was determined using the method of Haug and Lantzsch.[12] Diet, digesta and fecal samples were analyzed for calcium and phosphorus according to the AOAC procedures.[9] Chromic oxide was analyzed as described by Williams *et al*.[13] Apparent ileal and total tract digestibilities were calculated using Cr as an indigestible index.

Calculations and statistical analysis

Apparent digestibility coefficients were calculated as described by Adeola.[14] Data were subjected to analysis of variance using the general linear model (GLM) procedures of SAS (SAS Institute Inc., Cary, NC, USA). The experimental design used was a replicated 3×3 Latin square and effects of period (d.f. = 2), animal (d.f. = 2), square (d.f. = 1) and diet (d.f. = 2) were included in the statistical model. When a significant F-value ($P < 0.05$) was indicated by the analysis of variance, means of diet treatments were compared using Duncan's multiple-range test.[15]

RESULTS AND DISCUSSION

The proximate composition and amino acid composition of the DDGS samples analyzed in the preliminary study are shown in Table 1. The obtained compositional profiles show that the analyzed DDGS samples have high levels of dry matter, crude protein, ether extract and gross energy compared with the amounts generally present in wheat. The composition of wheat-based DDGS, obtained from the same ethanol plant as the samples evaluated in the present study, has previously been reported by Boila and Ingalls.[5] In that study, the dry matter, nitrogen, ADF and NDF contents of those samples averaged 963, 69.8, 156 and 361 g kg^{-1}, respectively. These values are in close agreement with those obtained in the present study (Table 2). In addition, the amino acid composition in the samples evaluated by Boila and Ingalls[5] is largely similar to the composition of the current samples, although there were some differences in some amino acids, including lysine and threonine. The present data and that of Boila and Ingalls[5] show that wheat DDGS have a considerably higher fibre content than wheat, which may have negative implications on the use of these products as a feedstuff for swine, particularly

Table 2. Chemical and amino acid (g kg^{-1}) and energy (MJ kg^{-1}) composition of ingredients and diets used in the digestibility study (air dry basis)

	Ingredients[a]			Diets[a]		
Item	Wheat	DDGS-W	DDGS-M	Basal	DDGS-W	DDGS-M
Dry matter	923.5	956.4	960.4	928.1	942.8	937.1
Nitrogen	21.3	64.6	65.5	21.1	37.7	37.5
Gross energy	16.9	20.5	20.3	16.5	17.8	17.6
ADF	48.2	131.5	115.9	—	—	—
NDF	118.1	306.5	286.2	—	—	—
Ether extract	15.0	36.8	35.5	—	—	—
Ash	16.2	44.3	47.8	—	—	—
Total phosphorus	3.7	8.5	9.5	5.3	8.0	8.5
Phytate P	3.0	1.8	2.3	3.1	2.4	2.7
Calcium	0.6	1.6	1.4	4.7	5.7	5.8
Essential amino acids						
Arginine	5.56	15.15	15.43	5.43	9.12	9.53
Histidine	2.95	7.68	7.79	2.66	4.72	4.88
Isoleucine	5.21	12.82	13.46	3.96	6.72	7.73
Leucine	9.43	27.37	25.37	8.56	16.56	15.88
Lysine	3.40	6.76	6.52	3.80	4.88	5.25
Phenylalanine	5.83	18.78	17.92	6.00	10.74	10.88
Threonine	4.38	13.38	13.72	4.29	7.68	7.74
Valine	6.10	17.23	16.39	5.68	9.67	9.76
Non-essential amino acids						
Alanine	4.74	13.56	13.50	4.27	8.49	8.18
Aspartate	7.95	21.49	21.34	7.24	12.88	12.66
Glutamate	41.34	114.42	122.02	39.17	73.53	78.34
Glycine	5.96	16.01	17.82	5.64	10.12	10.53
Proline	12.94	33.43	36.00	13.61	22.86	25.52
Serine	6.50	19.93	20.32	6.36	12.02	12.23
Tyrosine	3.60	11.19	11.39	3.55	6.44	6.77

[a] DDGS-W, winter wheat dried distiller's grains with solubles; DDGS-M, mixed wheat dried distiller's grains with solubles.

young swine. Various studies have shown that high dietary fibre reduces feed intake and nutrient utilization in pigs.[16] However, considering that the DDGS samples had very high contents of gross energy, nitrogen and amino acids, there is potential for this material to be used as a feed ingredient in pig feeds. This will only be possible, however, after estimates of the bioavailability of these nutrients for pigs have been determined.

A consistent nutritional profile of an ingredient is an important determinant of its acceptance for routine use in commercial feed formulation. The chemical composition data in the present study show important batch-to-batch differences in the content of some nutrients like nitrogen (range 52.6–65.5 $g\,kg^{-1}$). This variability may be due to various factors including the source of the raw material, differences in wheat cultivars, quality control of the fermentation process, how much solubles are added back into the distiller's grains and the completeness of fermentation from batch to batch.[17] This observation underlines the significance of developing technologies to optimize the DDGS production process to assure consistency in its nutritional profile.

The chemical and amino acid composition of the samples used in the digestibility study are shown in Table 2. The composition of the wheat used in the present study was very similar to published composition.[2] In general, the DDGS samples contained about three times the contents of the various nutrients compared with wheat, which is consistent with the results obtained with corn DGGS.[17] This observation is explained by the fact that, during the fermentation process, starch is converted to alcohol and carbon dioxide, which upon removal leaves material with concentrated levels of other components. The DDGS samples had higher ADF and NDF contents than wheat, which may impact on their energy supply to swine. However, DDGS had higher GE content than wheat, which probably is the reflection of the increased fat content in DDGS compared with wheat (36.2 vs 15.0 $g\,kg^{-1}$; Table 2).

The AID coefficients of the various components are shown in Table 3. Wheat had higher ($P < 0.05$) apparent ileal dry matter, nitrogen and gross energy digestibilities compared with the two wheat-based DDGS samples. The digestibility coefficients for these components were similar in the two DDGS samples and averaged 0.411, 0.689 and 0.473 for dry matter, nitrogen and gross energy, respectively (Table 3). The low dry matter and energy digestibility in the DDGS samples was probably caused by the high fibre content in these samples. Although differences in apparent ileal phosphorus and calcium digestibilities were not significant ($P > 0.05$), the coefficients for the DDGS samples were about 30% higher than those obtained for wheat. It has been suggested that phosphorus in corn DDGS is more available to pigs compared with the phosphorus in corn grains.[1,18] The non-phytate phosphorus content in the DDGS samples was much higher than in wheat (Table 2), which is the likely explanation for the higher phosphorus digestibility in DDGS.

Table 3. Apparent ileal digestibility coefficients of nutrients

Parameter	Wheat	DDGS-W[a]	DDGS-M[a]	SD[b]
Dry matter	0.781a	0.429b	0.393b	0.065
Nitrogen	0.813a	0.686b	0.691b	0.033
Gross energy	0.790a	0.493b	0.453b	0.061
Phosphorus	0.426	0.527	0.578	0.062
Calcium	0.451	0.644	0.726	0.131
Essential amino acids				
Arginine	0.864a	0.757b	0.790b	0.043
Histidine	0.851a	0.706b	0.744b	0.037
Isoleucine	0.848a	0.640c	0.719b	0.034
Leucine	0.867a	0.778b	0.777b	0.028
Lysine	0.761a	0.423b	0.452b	0.078
Phenylalanine	0.884a	0.825b	0.833b	0.024
Threonine	0.723a	0.607b	0.650ab	0.061
Valine	0.816a	0.667b	0.674b	0.045
Non-essential amino acids				
Alanine	0.759a	0.651b	0.659b	0.039
Aspartate	0.765a	0.501b	0.515b	0.049
Glutamate	0.938a	0.850b	0.858b	0.017
Glycine	0.760a	0.591b	0.637b	0.050
Proline	0.891	0.816	0.822	0.067
Serine	0.836a	0.734b	0.751b	0.032
Tyrosine	0.864a	0.787b	0.818b	0.029

[a] As in Table 2.
[b] Pooled standard deviation.
Mean values within a row not sharing a common letter are significantly different ($P < 0.05$).

The AIDs of amino acids for wheat were close to some published values[2,19] and considerably higher than others.[20,21] For all amino acids except proline, ileal digestibilities in wheat were higher ($P < 0.05$) than in winter wheat DDGS. For the mixed wheat DDGS, ileal digestibilities were similar to wheat only for threonine and proline; digestibilities for all other amino acids were lower ($P < 0.05$) compared with wheat. There were no differences in ileal amino acid digestibility between the DDGS samples, except for isoleucine, whose digestibility was higher ($P < 0.05$) in the mixed wheat DDGS sample. Data on amino acid digestibility in wheat-based DDGS fed to pigs are scarce, making it difficult to make comparisons with the present data. However, the present data showing lower amino acid digestibilities in DDGS compared with wheat are consistent with previous reports showing lower nutrient digestibilities in corn-based DDGS compared with corn.[2] The lower AID of nitrogen and amino acids in DDGS may be attributed largely to increased endogenous nitrogen and amino acid flow at the distal ileum due to the high fibre content, as discussed by Schulze *et al*[22] and Nyachoti *et al*.[23]

The apparent total tract digestibility coefficients of nutrients are shown in Table 4 and followed the same pattern as seen at the ileal level. The fecal digestibility coefficients for dry matter, nitrogen and gross energy

Table 4. Apparent total tract digestibility coefficients of nutrients

Parameter	Wheat	DDGS-W[a]	DDGS-M[a]	SD[b]
Dry matter	0.868a	0.647c	0.665b	0.010
Nitrogen	0.868a	0.765b	0.747c	0.001
Gross energy	0.862a	0.653c	0.679b	0.012
Phosphorus	0.436	0.502	0.552	0.120
Calcium	0.518	0.522	0.700	0.115

[a] As in Table 2.
[b] Pooled standard deviation.
Mean values within a row not sharing a common letter are significantly different ($P < 0.05$).

were higher ($P < 0.05$) in wheat compared with wheat DDGS. The apparent fecal digestibilities for nitrogen and energy obtained in the current study are in close agreement with those reported by Zijlstra *et al*.[24] Mixed wheat DDGS had higher ($P < 0.05$) fecal dry matter and gross energy digestibility than winter wheat DDGS; there was no difference in fecal nitrogen digestibility between the DDGS samples. Similarly, fecal calcium and phosphorus digestibility did not differ among ingredients ($P > 0.05$). Fecal phosphorus digestibility coefficients were very similar to the values determined at the ileal level, suggesting that the large intestine does not play a major role in overall phosphorus utilization in swine. This observation is consistent with previous reports.[25,26]

The apparent ileal and fecal digestible nutrient contents in wheat and wheat-based DDGS are summarized in Tables 5 and 6, respectively. Apparent ileal digestible dry matter content in wheat DDGS averaged 394 g kg^{-1} compared with 721 g kg^{-1} in wheat (Table 5). The average apparent ileal and fecal DE content in wheat DDGS was 9.65 and 13.50 MJ kg^{-1}, respectively (Tables 5 and 6). Corresponding values recently reported by Widyaratne *et al*[6] for wheat DDGS from the same ethanol plant were 11.84 and 13.95 MJ kg^{-1}, respectively. While estimates of fecal DE from the two studies are almost identical, the ileal DE value obtained in the present study is lower. This may be due to the age difference of the pigs used in the two studies; Widyaratne *et al*[6] used pigs weighing approximately 65 kg, whereas the pigs used in the present study weighed approximately 30 kg. Overall, the present results indicate that the DE content in wheat DDGS is about 7.5% lower than the DE content in wheat. According to the NRC,[2] corn DDGS have about 9.2% less DE content compared with grain corn.

With respect to dietary amino acid supply in pig diets, it is well accepted that ileal digestible values should be used.[27] Results of the present study show that wheat-based DDGS had higher ($P < 0.05$) ileal digestible amino acid content compared with wheat (Table 5). The ileal digestible lysine and threonine contents in the wheat DDGS averaged 2.9 and 8.5 g kg^{-1}, respectively, which closely agrees with respective values of 3.0 and 8.8 g kg^{-1} for lysine and threonine reported by Widyaratne *et al*.[6] Because of

Table 5. Apparent ileal digestible contents of energy (MJ kg^{-1}) and nutrients (g kg^{-1})

Parameter	Wheat	DDGS-W[a]	DDGS-M[a]	SD[b]
Dry matter	721.3a	410.6b	377.2b	50.48
Nitrogen	17.3b	44.3a	45.3a	1.86
Energy	13.3a	10.1b	9.2b	0.96
Phosphorus	1.58b	4.03a	5.10a	0.34
Calcium	0.25	1.07	0.95	0.19
Essential amino acids				
Arginine	4.8b	11.5a	12.2a	0.63
Histidine	2.5b	5.4a	5.8a	0.24
Isoleucine	4.4c	8.2b	9.7a	0.53
Leucine	8.2c	21.7a	19.7b	0.81
Lysine	2.6	2.9	2.9	0.38
Phenylalanine	5.2b	15.5a	14.9a	0.46
Threonine	3.2b	8.1a	8.9a	0.66
Valine	5.0b	11.5a	11.0a	0.77
Non-essential amino acids				
Alanine	3.6b	8.8a	8.9a	0.58
Aspartate	6.1b	10.8a	11.0a	0.94
Glutamate	38.8c	97.3b	104.7a	1.81
Glycine	4.5c	9.5b	11.2a	0.72
Proline	11.5c	27.3b	29.6a	1.23
Serine	5.4b	14.6a	15.3a	0.48
Tyrosine	3.1b	8.8a	9.3a	0.34

[a] As in Table 2.
[b] Pooled standard deviation.
Mean values within a row not sharing a common letter are significantly different ($P < 0.05$).

Table 6. Apparent total tract digestible energy (MJ kg−1) and nutrient (g kg^{-1}) content

Parameter	Wheat	DDGS-W[a]	DDGS-M[a]	SD[b]
Dry matter	801.3a	618.4c	638.7b	16.0
Nitrogen	18.5b	49.4a	49.0a	1.74
Energy	14.6a	13.4b	13.6b	0.48
Phosphorus	1.63b	4.90a	5.07a	0.76
Calcium	0.32b	0.96a	0.98a	0.16

[a] As in Table 2.
[b] Pooled standard deviation.
Mean values within a row not sharing a common letter are significantly different ($P < 0.05$).

the importance of lysine as the first limiting amino acid in most swine diets, it will be of interest to clearly identify the factor(s) responsible for the lower proportion of total lysine in wheat DDGS that is digested at the ileal level in pigs. One will expect that the procedures used in drying the distilled grains may be the main contributing factor because under high heat treatment lysine easily undergoes Maillard reactions with carbohydrates, which leads to its reduced bioavailability.[28] The ethanol plant from which the DDGS samples were obtained dries the distillers' grains using dry heat.

The results of the present study show that wheat DDGS contains high levels of nutrients including energy, protein, amino acids and non-phytate phosphorus. However, as this feedstuff contains a high fibre content, more studies must be completed to gain a better understanding of how the high fibre content might influence the feed value of wheat DDGS for swine. Although the digestibility data show high digestible contents of the various nutrients in DDGS relative to wheat, the digestibility coefficients for most nutrients, including key amino acids such as lysine and threonine, were quite low. Causes of such low digestibilities must be identified to allow development of means of improving the nutritive value of wheat DDGS for swine. It is concluded that wheat DDGS could be effectively utilized in pig diets; however additional research is required to fully characterize its nutritive value in terms of nutrient availability and pig performance measurements and to explore means of enhancing its nutritive value.

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