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Effects of Supplementary Threonine, Canola Oil or Enzyme on Nutrient Digestibility, Performance and Carcass Traits of Growing-finishing Pigs Fed Diets Containing Wheat Distillers Grains with Solubles

P. A. Thacker*
Department of Animal Science, University of Saskatchewan, 51 Campus Drive,
Saskatoon, Saskatchewan, Canada, S7N 5A8

ABSTRACT : This trial was conducted to determine the effects of various feed additives on nutrient digestibility, performance and carcass traits of growing-finishing pigs fed diets containing wheat distiller's grains with solubles (WDGS). Seventy-two, individually fed pigs (19.7±2.6 kg), were assigned to one of six dietary treatments in a 6×2 (treatment×sex) factorial design (N = 12). The control diet was based on wheat and soybean meal while the five experimental diets contained 20% WDGS during the growing period and 12% WDGS during the finishing period. One 20% WDGS diet was unsupplemented while the remaining diets were supplemented with either 0.1% threonine, 5% canola oil, 0.2% enzyme (0.1% Endofeed W containing 1,250 units/g of xylanase and 385 units/g of β-glucanase and 0.1% Vegpro containing 7,700 HUT/g protease and 75 CMC/g cellulase), or a combination of the three additives at the same levels as those fed separately. The digestibility of dry matter, crude protein and energy were all significantly higher in the control diet than the unsupplemented diet containing 20% WDGS. None of the feed additives improved nutrient digestibility. In addition, none of the additives had any significant effect on gain or feed intake during the growing (19.7 to 43.6) or finishing (43.6 to 114.3 kg) periods or overall (19.7 to 114.3 kg). During the growing period, feed conversion was significantly improved for pigs fed the combination of additives compared with the unsupplemented WDGS diet. During the finishing period and overall, feed conversion was significantly improved for pigs fed 5% canola oil alone or in combination with the other additives. None of the supplements had any effect on carcass traits. These results indicate that WDGS can be successfully used as a partial replacement for soybean meal in diets fed to growing-finishing pigs. However, due to its low energy content, there may be some merit in including high energy ingredients such as canola oil when diets containing WDGS are fed. (**Key Words :** Pigs, Digestibility, Performance, Carcass, Wheat Distillers Grains with Solubles)

INTRODUCTION

There is increasing interest in using cereal grains to produce ethanol for use in motor fuel. In order to produce ethanol, grain is milled, mixed with water and cooked (Shurson et al., 2004). Enzymes are added to the mixture to convert starch to sugar and the sugar is fermented by the addition of yeast (Ingledew, 1993). After complete fermentation, the ethanol is removed by distillation and the remaining fermentation residues are dried and used for livestock feed (Shurson et al., 2004). Historically, two residual products have been produced during ethanol production, namely distiller's dried grains and distiller's dried solubles. However, most ethanol plants now blend these two residues in order to produce distiller's dried grains with solubles and they are the most common by-product available from the ethanol industry.

Corn is the most common substrate used for ethanol production due to its abundance and its high yield of ethanol. Corn distiller's dried grains with solubles are typically used in diets fed to ruminants (Ham et al., 1994; Lodge et al., 1997) although several research trials have indicated that they also have the potential to be included in diets formulated for swine (Wahlstrom et al., 1970; Cromwell et al., 1993; Spiehs et al., 2002).

In areas of the world where corn is not available, wheat is the most common substrate used to produce ethanol but the nutritional value of wheat distiller's dried grains with solubles (WDGS) has not been extensively studied. In a

* Corresponding Author: P. A. Thacker. Tel: +1-306-966-4159, Fax: +1-306-966-4151, E-mail: phil.thacker@usask.ca
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preliminary study, the performance of growing pigs (20-50 kg) fed diets containing high levels (15-25%) of WDGS was significantly poorer than that of pigs fed soybean meal as the sole source of supplementary protein (Thacker, 2006).

Diets containing WDGS can be marginally deficient in threonine (Thacker, 2006) which may result in an imbalance of essential amino acids. Therefore, diets containing wheat DDGS may benefit from supplementation with synthetic threonine. In addition, the digestible energy content of WDGS is lower than soybean meal (Thacker, 2006). Lipid supplementation increases the energy content of swine diets (Stahly, 1984) and has been shown to improve the feeding value of high fibre diets fed to growing-finishing pigs (Myer and Combs, 1991) and therefore lipid supplementation may also have the potential to improve the performance of pigs fed WDGS.

The cell walls of cereal grains contain complex carbohydrates referred to as non-starch polysaccharides. In wheat, the principle non-starch polysaccharides are arabinoxylans, which are linear polymers of variable length consisting of D-xylose joined with β (1-4) linkages and single residues of arabinose attached along the primary xylan chain (Barrera et al., 2004). Arabinose renders this polymer soluble and can cause a viscous intestinal fluid that interferes with nutrient digestion and can potentially negatively affect pig performance (Thacker, 2000). Since the removal of starch in the distillation process will concentrate any anti-nutritional factor, the arabinoxylan level in WDGS is higher than that found in wheat (Widyaratne and Zijlstra, 2007). As a result, there may be greater potential for xylanase supplementation to improve the nutritive value of WDGS than for wheat.

In the near future, many new ethanol plants will be coming on stream in North American and elsewhere (Stein and Shurson, 2009). This in turn will lead to substantial quantities of WDGS being made available to the livestock industry for use as animal feed. The development of methods to improve the nutritional value of WDGS would benefit both the ethanol and livestock industries. This feeding trial was conducted to determine the effects of supplementary threonine, canola oil or enzyme on performance and carcass traits of growing-finishing pigs fed diets containing WDGS.

MATERIALS AND METHODS

Acquisition of wheat distiller's grains with solubles

The WDGS used in this study were obtained from New Life Feeds (Saskatoon, Saskatchewan) and were produced at the Husky/Mohawk ethanol plant located in Minnedosa, Manitoba. A chemical analysis of the main ingredients used in the feeding trial is shown in Table 1.

Table 1. Chemical analysis of main ingredients used to determine the effects of various feed additives on the nutritional value of wheat distillers grains with solubles (WDGS)[1]

	Wheat	WDGS	Soybean meal
Chemical composition (% as fed)			
Moisture	10.31	7.35	7.89
Crude protein	14.21	35.67	47.43
Ash	2.07	4.61	6.54
Ether extract	1.44	5.38	1.04
Neutral detergent fiber	14.16	33.16	8.67
Calcium	0.05	0.18	0.34
Phosphorus	0.33	0.91	0.72
Gross energy (kcal/kg)	4,436	4,724	4,339
Digestible energy (kcal/kg)[2]	3,418	3,118	3,734
Essential amino acids (% as fed)			
Arginine	0.82	1.59	3.58
Histidine	0.40	0.77	1.21
Isoleucine	0.62	1.42	2.41
Leucine	1.08	2.45	3.91
Lysine	0.53	0.92	3.16
Methionine and cystine	0.74	1.50	1.70
Phenylalanine	0.29	1.03	1.48
Threonine	0.48	1.13	2.33
Valine	0.28	1.64	2.44

[1] All chemical composition data are the results of a chemical analysis conducted in duplicate.

[2] Digestible energy calculated using the equation DE (kcal/kg) = 949+(0.789×gross energy)-(43×% ash)-(41×% NDF) taken from NRC (1998).

Table 2. Ingredient composition and chemical analysis of growing diets (19.7-43.6 kg) formulated to determine the effects of various feed additives on the nutritive value of wheat distillers grains with solubles (WDGS)[1]

	Level of wheat distillers grains with solubles (%)					
	Wheat	20% WDGS	20% WDGS +canola oil	20% WDGS +enzyme	20% WDGS +threonine	20% WDGS +combination
Ingredients (%)						
Wheat (14.21% CP)	79.69	69.97	63.51	69.77	69.87	63.21
WDGS (35.67% CP)	0.00	20.00	20.00	20.00	20.00	20.00
Soybean meal (47.43% CP)	15.31	4.55	6.01	4.55	4.55	6.01
Limestone	0.96	0.96	0.96	0.96	0.96	0.96
Dicalcium phosphate	1.15	1.15	1.15	1.15	1.15	1.15
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin-mineral premix	1.00	1.00	1.00	1.00	1.00	1.00
Lysine	0.25	0.53	0.53	0.53	0.53	0.53
Canola oil	1.14	1.34	6.34	1.34	1.34	6.34
Enzyme	0.00	0.00	0.00	0.20	0.00	0.20
Threonine	0.00	0.00	0.00	0.00	0.10	0.10
Chemical analysis (% as fed)						
Moisture	12.02	11.21	10.36	11.10	10.13	10.38
Ash	4.60	4.52	4.52	4.51	4.39	4.61
Crude protein	18.79	19.07	19.01	19.03	19.69	19.11
Neutral detergent fibre	9.01	11.95	12.40	11.69	11.90	12.01
Ether extract	4.62	4.63	9.74	5.17	4.75	8.38
Calcium	0.68	0.70	0.67	0.69	0.69	0.68
Phosphorus	0.62	0.63	0.60	0.63	0.61	0.59

[1] All chemical composition data are the results of a chemical analysis conducted in duplicate.

Growth trial

The pigs used in this study were housed and managed according to the Canadian Council on Animal Care (1993) guidelines. Seventy-two, individually fed, crossbred pigs (Camborough 15 Line female × Canabred sire, Pig Improvement Canada Ltd., Airdrie Alberta), weighing 19.7 ± 2.6 kg, were assigned on the basis of sex, weight and litter to one of six dietary treatments in a 6×2 (treatment× sex) factorial design (N = 12). The control diet was based on wheat and soybean meal while the five experimental diets contained 20% WDGS during the growing period (Table 2) and 12% WDGS during the finishing period (Table 3). The inclusion of 12% WDGS allowed for the complete removal of soybean meal from the ration during the finishing period.

One WDGS diet was unsupplemented while the four remaining diets were supplemented with either 0.1% L-threonine (Ajinomoto Animal Nutrition, Eddyville, IA), 5% canola oil (Cargill Crush Plant, Clavet, Saskatchewan), 0.2% of an enzyme cocktail comprised of 0.1% Allzyme Vegpro (Alltech Biotechnology Centre, Nicholasville, Kentucky) and 0.1% Endofeed W (GNC Bioferm Incorporated, Saskatoon, Saskatchewan), or a combination of threonine, canola oil and enzyme fed at the same levels as those used separately. The enzymes used were commercially available products. Endofeed W provided 1,250 units/g of xylanase and 385 units/g of β-glucanase. The enzyme Allzyme Vegpro provided 7,700 HUT/g protease and 75 CMC/g cellulase as well as lesser quantities of xylanase, α-galactosidase and amylase.

During the growing period (19.7 to 43.6 kg), the experimental diets were formulated to supply 3,350 kcal/kg DE and 0.95% lysine while in the finishing period (43.6 to 114.3 kg), the diets were formulated to supply approximately 3,280 kcal/kg DE and 0.75% lysine. Synthetic lysine was added to ensure that all diets provided a similar balance of amino acids (Table 4). All diets were supplemented with sufficient vitamins and minerals to meet or exceed the levels recommended by the National Research Council (NRC, 1998). The diets were pelleted using low-pressure steam at approximately 60°C.

The pigs were housed in unisex groups of four in 2.7 × 3.6 m concrete floored pens and provided water *ad libitum*. The pens were equipped with four individual self-feeders located in a 500×1,200 mm area located at the front of each pen. The pigs were locked into the feeding station for 30-min twice daily (07:00 h and 15:00 h). The pigs and feeders were colour coded and only one pig was ever allowed access to an individual feeder. Individual body weight, feed consumption and feed conversion were recorded weekly. Six castrates and six gilts were fed each diet.

Table 3. Ingredient composition and chemical analysis of finishing (43.6-114.3 kg) diets formulated to determine the effects of various feed additives on the nutritive value of wheat distillers grains with solubles (WDGS)[1]

	Level of wheat distillers grains with solubles (%)					
	Wheat	20% WDGS	20% WDGS +canola oil	20% WDGS +enzyme	20% WDGS +threonine	20% WDGS +combination
Ingredients (%)						
Wheat (14.21% CP)	88.56	84.25	79.25	84.05	84.15	78.95
WDGS (35.67% CP)	0.00	12.00	12.00	12.00	12.00	12.00
Soybean meal (47.43% CP)	7.94	0.00	0.00	0.00	0.00	0.00
Limestone	1.06	1.10	1.10	1.10	1.10	1.11
Dicalcium phosphate	0.71	0.71	0.71	0.71	0.71	0.71
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin-mineral premix	1.00	1.00	1.00	1.00	1.00	1.00
Lysine	0.23	0.44	0.44	0.44	0.44	0.44
Canola oil	0.00	0.00	5.00	0.00	0.00	5.00
Enzyme	0.00	0.00	0.00	0.20	0.00	0.20
Threonine	0.00	0.00	0.00	0.00	0.10	0.10
Chemical analysis (% as fed)						
Moisture	11.99	11.34	11.13	11.86	11.86	11.62
Ash	3.89	3.84	3.77	3.84	3.77	3.67
Crude protein	16.81	16.50	16.18	16.27	16.53	15.82
Neutral detergent fibre	8.82	11.27	11.94	11.40	11.29	11.03
Ether extract	1.40	2.34	7.15	2.45	2.03	7.25
Calcium	0.62	0.60	0.58	0.62	0.60	0.57
Phosphorus	0.48	0.49	0.47	0.49	0.49	0.47

[1] All chemical composition data are the results of a chemical analysis conducted in duplicate.

Table 4. Amino acid analysis (% as fed) of diets formulated to determine the effects of various feed additives on the nutritive value of wheat distillers grains with solubles (WDGS)[1]

	Wheat	20% WDGS	20% WDGS +canola oil	20% WDGS +enzyme	20% WDGS +threonine	20% WDGS +combination
Growing diets (19.7 to 43.6 kg)						
Arginine	1.02	0.90	0.86	0.90	1.01	0.88
Histidine	0.47	0.44	0.43	0.45	0.46	0.44
Isoleucine	0.74	0.69	0.69	0.70	0.68	0.70
Leucine	1.30	1.26	1.25	1.28	1.27	1.28
Lysine	0.97	1.00	0.98	1.05	1.00	1.05
Methionine+cystine	0.71	0.73	0.71	0.73	0.74	0.75
Phenylalanine	0.41	0.41	0.43	0.42	0.43	0.42
Threonine	0.60	0.57	0.57	0.57	0.65	0.67
Valine	0.81	0.82	0.79	0.80	0.80	0.81
Finishing diets (43.6 to 114.3 kg)						
Arginine	0.73	0.67	0.60	0.67	0.70	0.70
Histidine	0.39	0.39	0.34	0.38	0.37	0.36
Isoleucine	0.63	0.59	0.54	0.62	0.61	0.57
Leucine	1.18	1.15	1.03	1.17	1.12	1.07
Lysine	0.76	0.80	0.77	0.80	0.80	0.80
Methionine+cystine	0.67	0.67	0.69	0.66	0.66	0.68
Phenylalanine	0.86	0.87	0.80	0.87	0.85	0.81
Threonine	0.53	0.53	0.49	0.53	0.58	0.62
Valine	0.78	0.79	0.71	0.78	0.76	0.73

[1] All chemical composition data are the results of an amino acid analysis conducted in duplicate.

Digestibility determination

Total tract digestibility coefficients for dry matter, crude protein and gross energy were determined using five barrows per treatment starting at an average weight of 37.3 ±2.6 kg. The pigs were housed under identical conditions as those used in the growth trial and were fed the same diets as those used during the growing stage modified only by the addition of 0.35% chromic oxide as a digestibility marker. The marked feed was provided for a seven-day acclimatization period, followed by a three-day fecal collection. Fecal collections were made by bringing the pigs into a clean room, immediately after feeding, and recovering freshly voided feces. The fecal samples were frozen for storage. Prior to analysis, the samples were dried in a forced air oven dryer at 66°C for 60 h, followed by fine grinding (0.5-mm screen). The digestibility coefficients for dry matter, crude protein and energy were determined using the equations for the indicator method described by Schneider and Flatt (1975).

Carcass measurements

The pigs were slaughtered at a commercial abattoir at an average weight of 114.3±4.2 kg. Carcass weight was recorded and dressing percentage calculated. Carcass fat and lean proportion measurements were obtained with a Destron probe (Model PG-100, Anitech Identification System Inc., Ottawa, Canada) probe placed over the 3rd and 4th last ribs, 70 mm off the midline. These values were then used in calculating Carcass Value Indices according to the table of differentials in effect at the time of the experiment (Saskatchewan Pork International, 2003).

Chemical analysis

Samples of the growing and finishing rations as well as fecal samples were chemically analysed according to the methods of the Association of Official Analytical Chemists (1990). Analyses were conducted for moisture (AOAC method 930.15), crude protein (AOAC method 984.13), ash (AOAC method 942.05) and ether extract (AOAC method 920.39). Neutral detergent fibre was analyzed using the method of Van Soest et al. (1991). The calcium and phosphorus content of the experimental rations were determined using the nitric-perchloric acid digestion method of Zasoski and Burau (1977) with calcium determined on a Perkin-Elmer Model 4000 Atomic Absorption Spectrophotometer (AOAC method 968.08) and total phosphorus determined colorimetrically (Pharmacia LKB Ultrospec III) using a molybdovanadate reagent (AOAC method 965.17).

An adiabatic oxygen bomb calorimeter (Parr; Moline, Illinois, USA) was used to determine gross energy content. Chromic oxide was determined by the method of Fenton and Fenton (1979). The amino acid content of the diets and ingredients were determined by High Performance Liquid Chromatography (Hitachi L-8800 Amino Acid Analyzer, Tokyo, Japan). All samples were hydrolyzed for 24 h at 110°C with 6 N HCl prior to analysis. Sulphur-containing amino acids were analyzed after cold formic acid oxidation for 16 h before acid hydrolysis.

Statistical analysis

All performance and carcass data were analysed as a 6×2 factorial design using the General Linear Models procedure of the Statistical Analysis System Institute, Inc. (SAS, 1999) with the factors in the model consisting of treatment, sex and their interaction. Digestibility data were analyzed as a one-way ANOVA. Where appropriate, treatment means were compared using Student-Newman-Keul's procedure. Differences were considered significant when $p<0.05$. Since the pigs were fed individually, they were considered the experimental unit for all statistical analysis and pen was never considered in any analytical model.

RESULTS

Nutrient analysis

The chemical analyses of the main ingredients used in this experiment are shown in Table 1. As a result of the removal of starch during the fermentation process, the nutrient content of the WDGS was approximately two to three fold higher than wheat. In terms of amino acids, WDGS provided lower levels of all of the essential amino acids than soybean meal. Of particular importance are the lower levels of lysine (0.92 vs. 3.16%) and threonine (1.13 vs. 2.33%) in WDGS relative to soybean meal.

The chemical analysis conducted on the growing and finishing rations confirmed that the diets met the specifications called for in the diet formulation. All diets contained approximately the same crude protein content (Tables 2 and 3). The neutral detergent fibre and ether extract content of the diets increased as the inclusion level of WDGS in the diet increased, reflecting the higher level of these two fractions in the test ingredient.

Nutrient digestibility

The digestibility of dry matter, crude protein and energy were all significantly higher in the wheat based control diet than the unsupplemented diet containing 20% WDGS (Table 5). None of the feed additives significantly improved nutrient digestibility compared with the control or the unsupplemented WDGS diet.

Pig performance

None of the additives had any significant effect on weight gain or feed intake during either the growing or

Table 5. The effects of various feed additives on the digestibility of dry matter, crude protein and energy for pigs fed diets containing wheat distillers grains with solubles (WDGS)[1]

	Wheat	20% WDGS	20% WDGS +canola oil	20% WDGS +enzyme	20% WDGS +threonine	20% WDGS +combination	SEM	p value
Dry matter (%)	84.30[a]	77.92[b]	80.53[b]	77.24[b]	79.35[b]	80.27[b]	0.89	<0.01
Crude protein (%)	81.08[a]	73.58[b]	77.44[b]	75.58[b]	76.14[b]	77.00[b]	1.14	<0.01
Energy (%)	83.38[a]	76.48[b]	80.22[ab]	76.66[b]	78.33[b]	80.27[ab]	1.02	<0.01

[1] Means followed by same or no letter do not differ (p>0.05).

finishing periods or during the overall experiment (Table 6). During the growing period, feed conversion was significantly improved for pigs fed the combination of additives compared with the unsupplemented WDGS diet. During the finishing period and overall, feed conversion was significantly improved for pigs fed the diet containing 5% canola oil alone or in combination with the other additives. During the growing period, sex of pig had no effect on pig performance. During the finishing period and overall, barrows had significantly higher weight gain and feed intake but poorer feed conversion than gilts.

Carcass traits

None of the supplements had any effect on dressing percentage, carcass value index, lean yield, loin fat or loin lean (Table 7). Gilts had a significantly lower slaughter weight and a significantly higher dressing percentage than barrows.

DISCUSSION

Chemical analysis

Soybean meal is the most widely used source of supplementary protein for swine production and is the common standard used to judge any alternative protein source. Therefore, a comparison of the chemical composition of soybean meal and WDGS seems warranted. The crude protein content of the WDGS was 35.7% which is lower than the crude protein content of soybean meal (47.4% CP). Therefore, higher levels of WDGS would have to be utilized when supplementing a swine ration than are required when supplementing with soybean meal. The digestible energy content of WDGS was lower than that of soybean meal (3,118 vs. 3,734 kcal/kg). This reduction in digestible energy can largely be attributed to the higher (33.16 vs. 8.67%) neutral detergent fibre level in WDGS compared with soybean meal. The higher (5.38 vs. 1.04%)

Table 6. Effects of various feed additives on the performance of growing-finishing pigs fed diets containing wheat distillers grains with solubles (WDGS)[1]

	Dietary treatment							Sex of pig			p values		
	Wheat	20% WDGS	20% WDGS +canola oil	20% WDGS +enzyme	20% WDGS +threonine	20% WDGS +combo	SEM	Barrow	Gilt	SEM	Treat	Sex	T×S
Growing period (19.7 to 43.6 kg)													
Weight gain (kg/d)	0.70	0.67	0.65	0.72	0.69	0.69	0.032	0.71	0.66	0.018	0.67	0.10	0.10
Feed intake (kg/d)	1.29	1.28	1.19	1.32	1.26	1.21	0.060	1.29	1.23	0.034	0.59	0.20	0.72
Feed conversion	1.85[ab]	1.93[a]	1.86[ab]	1.84[ab]	1.84[ab]	1.76[b]	0.027	1.83	1.86	0.015	<0.01	0.23	<0.01
Finishing period (43.6 to 1,143 kg)													
Weight gain (kg/d)	1.01	0.99	1.03	1.04	1.06	1.02	0.032	1.12	0.92	0.018	0.74	<0.01	0.90
Feed intake (kg/d)	2.78	2.72	2.59	2.81	2.78	2.57	0.079	3.00	2.41	0.045	0.17	<0.01	0.59
Feed conversion	2.74[a]	2.74[a]	2.51[b]	2.69[a]	2.63[ab]	2.53[b]	0.039	2.67	2.61	0.023	<0.01	0.04	0.06
Overall experiment (19.7 to 1,14.3 kg)													
Weight gain (kg/d)	0.91	0.88	0.90	0.93	0.93	0.91	0.026	0.97	0.85	0.015	0.69	<0.01	0.87
Feed intake (kg/d)	2.28	2.24	2.11	2.30	2.25	2.11	0.057	2.39	2.04	0.033	0.09	<0.01	0.55
Feed conversion	2.51[ab]	2.54[a]	2.35[c]	2.47[ab]	2.41[bc]	2.34[c]	0.029	2.46	2.42	0.016	<0.01	0.09	0.38

[1] Within dietary treatment or sex, means followed by same or no letter do not differ (p>0.05).

Table 7. Effects of various feed additives on carcass traits of growing-finishing pigs fed diets containing wheat distillers grains with solubles (WDGS)[1]

	Dietary treatment							Sex of pig			p values		
	Wheat	20% WDGS	20% WDGS +canola oil	20% WDGS +enzyme	20% WDGS +threonine	20% WDGS +combo	SEM	Barrow	Gilt	SEM	Treat	Sex	T×S
Slaughter weight (kg)	114.6	113.6	113.7	115.4	113.9	114.9	1.24	115.7	113.0	0.72	0.89	0.01	0.87
Carcass weight (kg)	91.2	91.0	91.4	90.8	89.9	91.2	1.06	91.4	90.4	0.61	0.94	0.26	0.92
Dressing percent (%)	79.6	80.2	80.4	78.7	79.0	79.4	0.42	79.0	80.0	0.25	0.05	0.01	0.58
Carcass value index	110.4	109.5	109.1	110.1	110.0	109.8	0.66	109.4	110.3	0.38	0.79	0.09	0.47
Lean yield (%)	60.4	59.7	59.1	59.8	60.7	60.2	0.46	59.7	60.2	0.27	0.23	0.20	0.42
Loin fat (mm)	19.3	20.6	21.9	19.8	18.9	19.8	1.05	20.5	19.6	0.61	0.40	0.31	0.46
Loin lean (mm)	62.0	60.0	58.9	58.1	64.1	63.1	1.81	59.8	62.3	1.05	0.15	0.11	0.85

[1] Within dietary treatment or sex, means followed by same or no letter do not differ ($p>0.05$).

ether extract content of WDGS relative to soybean meal may partially compensate for its higher fibre content. Nyachoti et al. (2005) previously reported a lower digestible energy value for WDGS compared with wheat.

In terms of amino acids, WDGS provided lower levels of all of the essential amino acids than did soybean meal. This finding supports the work of Widyartne and Zijlstra (2007) and Widyartne et al. (2009) who also reported low concentrations of lysine and threonine in WDGS.

The amino acid analysis of the growing and finishing diets confirmed that the diets met the requirements for pigs with a lean growth potential of 325 g/d (NRC, 1998). However, it should not be forgotten that during both the growing and finishing periods, lysine-HCl was added to the diets containing WDGS to ensure that all diets supplied approximately the same level of this first limiting amino acid. This finding supports our previous work, where substantial quantities of synthetic lysine were required in order to meet the lysine requirements of growing-finishing pigs when high levels of WDGS were included in the diet (Thacker, 2006).

Nutrient digestibility

The overall results of this experiment indicate that feeding 20% WDGS to growing-finishing pigs significantly reduces nutrient digestibility compared with feeding a wheat-soybean meal based diet. This finding supports our previous work (Thacker, 2006) and that of others (Nyachoti et al., 2005; Lan et al., 2008; Widyaratne et al., 2009) who reported reductions in nutrient digestibility of a similar magnitude to those observed in the present study when they fed WDGS to growing pigs. These findings are also consistent with other experiments where increasing dietary fibre has reduced nutrient digestibility (Kennelly and Aherne, 1980; Bell et al., 1983). It is thought that dietary fibre reduces nutrient digestibility due to its physiochemical properties, leading to a more rapid rate of passage which limits the amount of time available for nutrient breakdown (Burkitt et al., 1972).

Digestibility coefficients for pigs fed diets containing 20% WDGS supplemented with canola oil (both alone and in combination with the other additives) did not differ from those of pigs fed diets containing unsupplemented WDGS. As such, these results were somewhat surprising. However, previous experiments examining the effects of lipid supplementation on nutrient digestibility have produced equivocal results. Although Sauer et al. (1980) and Just (1982) reported improvements in nutrient digestibility with lipid supplementation, Lowrey et al. (1962) and Li and Sauer (1994) reported no changes. Where a positive effect has been obtained due to lipid supplementation, it has generally been attributed to a delay in gastric emptying which is postulated to slow rate of passage through the small intestine allowing more time for nutrient breakdown (den Hartog et al., 1989).

The protein in WDGS is poorly digested (Nyachoti et al., 2005; Thacker, 2006; Lan et al., 2008). Exposure to high temperatures during the drying process may be partially responsible for the reduction in protein digestibility as overheating can result in the production of Maillard reaction products which reduce amino acid availability (Gabert et al., 2001). Therefore, it was hypothesized that the addition of a protease enzyme may help to improve protein digestibility. Allzyme Vegpro contains protease and and has been shown to improve pig performance in some (Lindeman et al., 1997; Pluske and Lindeman, 1998) but not all cases (Thacker, 2001). However, in the present experiment, there was no change in protein digestibiltiy with the addition of the protease enzyme.

The cell walls of cereal grains contain complex carbohydrates referred to as non-starch polysaccharides. In wheat, the principle non-starch polysaccharides are arabinoxylans, which are linear polymers of variable length consisting of D-xylose joined with β (1-4) linkages, and single residues of arabinose attached along the primary xylan chain (Barrera et al., 2004). Arabinose renders this polymer soluble and can cause a viscous intestinal fluid that interferes with nutrient digestion and can potentially negatively affect pig performance.

Since the removal of starch in the distillation process will concentrate any anti-nutritional factor found in the grain, the arabinoxylan level in WDGS is higher than that found in wheat (Widyaratne and Zijlstra, 2007). As a result, it was expected that xylanase supplementation would improve the nutritive value of WDGS. However, in the present experiment, supplementation with an enzyme cocktail containing xylanase had no significant effect on nutrient digestibility. Widyaratne et al. (2009) also reported no benefit on digestibility due to xylanase supplementation and suggested that the processes of fermentation and drying used in the production of WDGS may change the nature of the arabinoxylans thereby preventing xylanase from being effective.

Supplementation of WDGS with threonine also had no effect on nutrient digestibility. However, this was to be expected as it would be difficult to come up with a plausible explanation as to why threonine supplementation should alter nutrient digestibility.

Pig performance

The significant reductions in nutrient digestibility were not accompanied by significant reductions in growing pig performance. These findings are similar to those of Widyaratne and Zijlstra (2006). In contrast, Thacker (2006) and Widyaratne et al. (2009) reported significant reductions in pig performance as a result of feeding WDGS to growing pigs.

The performance of finishing pigs fed WDGS was not affected to the same extent as the performance of growing pigs fed WDGS (Table 6) supporting the trend we observed in our previous study (Thacker, 2006). It is likely that the higher neutral detergent fibre content of diets containing higher levels of WDGS contributes to an increase in the bulkiness of the diet which places a physical limitation on appetite as gut capacity is reached (Cole and Chadd, 1989). The improved utilization of WDGS during the finishing period compared with the growing period can be attributed to the greater gut capacity of finishing pigs compared with growing pigs which removes the physical limitation on appetite caused by the higher fiber content of the WDGS. In addition, the ability to use dietary fibre increases between the late growing phase and young adulthood in pigs because of the greater number of cellulolytic organisms found in adults (Varel and Pond, 1985).

Inclusion of 5% canola oil (both alone and in combination with the other additives) in diets containing 20% WDGS significantly improved feed conversion compared with the unsupplemented 20% WDGS diet. In previous studies where improvements in feed conversion have been obtained as a result of lipid supplementation, the improvement was typically accompanied by a reduction in feed intake due to the greater density of lipid compared with carbohydrates or proteins (Azain, 2001). Although not significant, there was a trend towards decreased feed intake as a result of lipid inclusion in the present study.

Supplementation of WDGS with an enzyme cocktail containing xylanase had no significant effect on pig performance. Widyaratne et al. (2009) also reported no benefit on pig performance due to xylanase supplementation and suggested that the processes of fermentation and drying used in the production of WDGS may change the nature of the arabinoxylans thereby preventing xylanase from being effective. The failure of the wide range of enzymes included during the present trial to improve pig performance or increase nutrient digestibility provides little justification for the routine supplementation of pig diets containing WDGS with dietary enzymes.

The addition of threonine to the diet had no significant effects on pig performance. The NRC Growth Model (NRC, 1998) indicated that threonine may become marginally deficient in growing pig diets containing high levels (>10%) of WDGS. However, many factors affect amino acid requirements including genetic strain, gender, health, temperature, and stocking density (NRC, 1998). It is therefore possible that in the present trial, threonine was not deficient and therefore no response to threonine supplementation would be expected.

Carcass traits

There were no significant differences in carcass traits between pigs fed the control diet and the diet containing 20% WDGS. In addition, none of the supplements had any effect on dressing percentage, carcass value index, lean yield, loin fat or loin lean. In our previous work with WDGS (Thacker, 2006) a reduction in loin lean was observed when high levels of WDGS were included in the diet. Further research should be conducted to either confirm or refute the findings of potential negative effects on the carcass composition of growing-finishing pigs as a result of feeding WDGS.

CONCLUSION

In the present experiment, nutrient digestibility was significantly reduced when diets contained 20% WDGS, but the reduction in nutrient digestibility did not translate into negative effects on pig performance or carcass traits. Supplementation of diets containing 20% WDGS with 5% canola oil significantly improved feed conversion. Supplementation of diets containing WDGS with enzyme or threonine was ineffective in improving nutrient digestibility, pig performance or carcass traits. The overall results of this experiment indicate WDGS that can be successfully used as a partial replacement for soybean meal in diets fed to growing-finishing pigs. Due to its low energy content, there may be some merit in including high energy ingredients such as canola oil when diets containing WDGS are fed to growing-finishing pigs.

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