The effects of extrusion of wheat distillers dried grains with solubles with or without an enzyme cocktail on performance of turkey hen poults

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ABSTRACT Two experiments were conducted to determine if extrusion (EX) or enzymes (E) could overcome the restrictions (e.g., high fiber) of feeding wheat distillers dried grain with solubles (wDDGS) and improve its nutritional value for feeding turkeys. Two starter diets with either 0 or 30% wDDGS were formulated to meet or exceed the nutrient requirements of the Hybrid Converter female turkeys. The 30% wDDGS diet was substituted with either non-extruded (EX–) or extruded (EX+) wDDGS to produce three basal diets [0% wDDGS (EX–) or 30% wDDGS (EX–/EX+)]. Diets were blended to obtain 15% wDDGS. In the respective treatments, only wDDGS was extruded (temperature; 118°C, retention; 15 sec, total moisture; 25% and pressure 33 bar). The respective experimental diets were supplemented with/without an enzyme cocktail (E; 0.5 g/kg). Test diets were fed from 7–21 d in a completely randomized design. In Experiment 1, a total of 210 turkey hen poults were fed diets containing 0, 15, or 30% wDDGS (EX–) with or without enzyme (E+/E–). Body weight (BW) and feed intake (FI) were significantly higher for 0% wDDGSE–. Nitrogen retention (NR) and apparent metabolizable energy (AME) for the 30% wDDGSE– was significantly higher than other treatments at 21 d. The results indicated significant main effects of E and an interaction between wDDGS level and E. In Experiment 2, 280 turkey hen poults were fed 8 diets [15/30% wDDGS (E+/E–), (EX–/EX+)]. The level of wDDGS had a significant effect on BW, FI and gain:feed; 15% inclusion was superior to 30%. There were significant 2- and 3-way interactions for AME and NR at 21 d due to differences in enzyme response with 15 or 30% wDDGS inclusion and/or extrusion of wDDGS. As high as 15% wDDGS can be incorporated in turkey hen diets. There were no beneficial effects of EX or E on poult performance.

Key words: wheat distillers dried grains with solubles, extrusion, enzyme, digestibility, turkey

INTRODUCTION

The production of renewable energy as ethanol from cereal grains has increased over the years to supplement fuel requirements (Thacker and Widyaratne, 2007; Shalash et al., 2010). Wheat serves as the major substrate for ethanol production in Western Canada and some parts of Europe (Avelara et al., 2010). Ethanol production via wheat has accounted for the production of ~1.4 Million Metric Tonnes (MMT) of wheat distillers dried grains with solubles (wDDGS) from the biofuel industry (Ethanol Producer Magazine, 2013). This is available for use as a feed ingredient in poultry (Avelara et al., 2010; Dozier, 2012; Leeson, 2012). During ethanol production the ground cereal is converted into simple sugars via enzymatic action followed by fermentation with yeast to produce ethanol and the co-product DDGS and CO₂ (Rosentrater, 2006; Fallahi et al., 2013). There are limits to the inclusion of DDGS in monogastric diets due to high fiber and low amino acid level and availability (especially for lysine) (Lee et al., 2003; Lumpkins et al., 2004; Lim et al., 2009; Fallahi et al., 2013). There are also concerns about low energy due to the conversion of starch to ethanol (Kerr and Shurson, 2013) and the removal of fat from modern ethanol production (Wisner et al., 2013). Emerging technologies (e.g., feed processes or enzymes) may be employed to ensure effective utilization of the nutrients tightly bound to this high fiber and high protein co-product (Fallahi et al., 2013; Kerr and Shurson, 2013).

An enzyme cocktail or a multi-enzyme complex could more effectively degrade complex matrixes of fibrous carbohydrates or indigestible cell wall components of feed ingredients (Cowieson and Adeola, 2005; Emiola et al., 2009; Adeola and Cowieson, 2011; Kerr and Shurson, 2013). This will reduce their antinutritive effect, enhance digestion of nutrients, and subsequently improve performance in diets of monogastric animals (Cromwell et al., 1993; Emiola et al., 2009; deVries et al., 2012; Ziemer et al., 2012).

Extrusion has found application in aquaculture (Ayadi et al., 2011; Fallahi et al., 2013), human (Hood-Niefer and Tyler, 2010), and pet (Muthukumarappan, 2012) diets, as well as in, to a limited extent,
poultry and swine feeds (Fadel et al., 1988; Vukic-Vranjes et al., 1994; Vukic-Vranjes and Wenk, 1995; Gracia et al., 2003; Oryschak et al., 2010a, b). Extrusion is a hydrothermal process that uses combinations of temperature, moisture, pressure or shear, and mixing with variable time to modify the physical and nutrient structure of diets and/or ingredients (Fallahi et al., 2013). Ayadi et al. (2011) summarized the advantages of extrusion, including reduced antinutritional factors, improved palatability, and better digestibility. Oryschak et al. (2010a) reported that single screw extrusion of triticale DDGS significantly improved amino acid digestibility in poultry.

This study investigated the effects of extrusion and/or supplementation with or without an enzyme cocktail on the utilization of wDDGS diets by turkey hen poults.

**MATERIALS AND METHODS**

All procedures involving animal handling and testing were reviewed and approved by the University of Saskatchewan Committee on Animal Care and Supply (animal use protocol no. 19940248) and followed the principles established by the Canadian Council on Animal Care (1993).

**Test Ingredients and Extrusion Process**

The wDDGS used in the current experiment was a product from Husky ethanol processing plant (Lloydminster, Saskatchewan, Canada). The wDDGS used in the diets were either nonextruded (EX–) or extruded (EX+). The wDDGS was extruded using a twin-screw extruder (Clextral Evolum 32, Firminy, France) with a 4.88 mm diameter die at the Saskatchewan Food Industry Development Centre Inc. (Food Centre; 117–54 Innovation Boulevard Saskatoon, SK S7N 2V3, Canada). The extruder was powered by a 47.2-kW motor with a maximum screw speed of 496 rpm, a torque of 11 Nm and a pressure of 33 bar. There were 6 barrel zones with varying temperatures of 29, 80, 101, 119, 118, and 118°C, respectively. The wDDGS with an as-is moisture of 11.15% was extruded at a feeding rate of 54 kg/hr. The total residence time for extrusion was 2 s. Extrudates with total moisture of 25% then pass through a dryer (115°C for 2 min 25 s) for drying and cooling. The extrudates produced lacked an expected nugget form due to previous denaturing of the protein during ethanol production and drying of wDDGS.

**Particle Size Analysis**

To ensure a standard particle size, the extruded and nonextruded wDDGS were ground using a hammer mill (Glen Mills Inc., Clifton, NJ; University of Saskatchewan, College of Engineering) with a 4.76 mm screen size. Particle size analysis was accomplished using a rotary-tap testing sieve shaker (W. S. Tyler Industrial Group, Mentor, Ohio, USA 44060). Four replications per each wDDGS (weight: 300 g) source were used. The sieve mesh sizes used were US standard (12, 20, 30, 50, 60, and 100) representing 1680, 841, 594, 297, 250, and 150 microns, respectively. Mean particle size (Dgw) and standard deviation (Sgw) was determined for each sample (ASAE, 2012).

**Diets Formulation and Assay Diets**

Two diets containing 0% wDDGS or 30% wDDGS were formulated to either meet or exceed the nutrient requirements of Hybrid Conventional turkey starter diet. Diets were formulated based on digestible amino acids. The 30% contained either extruded (EX+) or nonextruded (EX–) wDDGS to produce 3 basal diets [0% wDDGS (EX–), 30% wDDGS (EX+) and 30% wDDGS (EX–); Table 1]. Only wDDGS was extruded in the respective mash diets. The diets were formulated to provide 27.5% CP, 2850 kcal of AME/kg, 1.62% lysine, 0.65% methionine, 1.40% calcium and 0.75% available phosphorus.

**Table 1.** Composition of experimental diets formulated to determine the effects of extrusion of wheat DDGS (wDDGS) with and/or without an enzyme cocktail (0.5 g/kg) on turkey hen poults’ performance.

<table>
<thead>
<tr>
<th>Ingredients (%)</th>
<th>0% wDDGS</th>
<th>30% wDDGS</th>
<th>Extruded Non-extruded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>47.19</td>
<td>37.83</td>
<td>37.83</td>
</tr>
<tr>
<td>Wheat DDGS</td>
<td>0.00</td>
<td>30.00</td>
<td>30.00</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>36.43</td>
<td>14.03</td>
<td>14.03</td>
</tr>
<tr>
<td>Fish meal</td>
<td>2.00</td>
<td>2.85</td>
<td>2.85</td>
</tr>
<tr>
<td>Corn-gluten meal</td>
<td>4.93</td>
<td>4.21</td>
<td>4.21</td>
</tr>
<tr>
<td>Canola oil</td>
<td>3.29</td>
<td>4.79</td>
<td>4.79</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.68</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Limestone</td>
<td>2.72</td>
<td>3.01</td>
<td>3.01</td>
</tr>
<tr>
<td>Salt</td>
<td>0.28</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Vitamin and mineral premix&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Choline chloride</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>DL-Methionine</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>L-Lysine</td>
<td>0.18</td>
<td>0.68</td>
<td>0.68</td>
</tr>
<tr>
<td>Celite</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Calculated nutrient levels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metabolizable Energy (kcal/kg)</td>
<td>2850</td>
<td>2850</td>
<td>2850</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>27.50</td>
<td>27.50</td>
<td>27.50</td>
</tr>
<tr>
<td>Canola oil (%)</td>
<td>5.11</td>
<td>8.33</td>
<td>8.33</td>
</tr>
<tr>
<td>Crude fiber (%)</td>
<td>2.65</td>
<td>4.04</td>
<td>4.04</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>1.40</td>
<td>1.40</td>
<td>1.40</td>
</tr>
<tr>
<td>Phosphorus (%)</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Sodium (%)</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Methionine (%)</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>Lysine (%)</td>
<td>1.62</td>
<td>1.62</td>
<td>1.62</td>
</tr>
<tr>
<td>Threonine (%)</td>
<td>1.04</td>
<td>0.94</td>
<td>0.94</td>
</tr>
</tbody>
</table>

<sup>1</sup>Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin d, 2200 IU; vitamin E (dl-α-tocopheryl acetate), 30 IU; menadione, 2 mg; thiamine, 1.5 mg; riboflavin, 6 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B<sub>12</sub>, 0.02 mg; pantothenic acid, 10 mg; folic acid, 0.6 mg; and biotin, 0.15 mg, iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; and selenium, 0.3 mg.
**Experiment 1.** In Experiment 1, 2 of the basal diets ([0% wDDGS (EX–) and 30% wDDGS (EX–)]) were equally mixed to obtain 15% wDDGS (EX–) inclusion. These diets (0% wDDGSEX–, 15% wDDGSEX– and 30% wDDGSEX–) were either supplemented with/without an enzyme cocktail ([Superzyme (E+); 0.5 g/kg, (Canadian Bio-System, 4389 112 Ave SE, Calgary, AB, T2C 0J7, Canada]) The enzyme supplied 1100 units/g of xylanase, 375 units/g of glu- canase, 350 units/g of invertase, 700 units/g of pro- tease, 1650 units/g of cellulase, 7250 units/g of amylase, 230 unit/g of mannanase and 25 units/g of galac- tanase. The six assay test diets in experiment 1 were 0% wDDGS (E–), 0% wDDGS (E+), 15% wDDGS (E–), 15% wDDGS (E+), 30% wDDGS (E–) and 30% wDDGS (E+).

**Experiment 2.** In experiment 2, the 0% wDDGS (EX–) and the 30% (EX–, EX+), were mixed into equal proportions to obtain 15% wDDGS (EX–, EX+). The 15 wDDGS (EX–, EX+), 30% (EX–, EX+) were then supplemented with/without an enzyme cocktail (similar to Experiment 1) and the eight assay diets fed in Experiment 2 were 15 wDDGS (EX–/E–), 15 wDDGS (EX+/E–), 15 wDD- GHS (EX+/E+), 30 wDDGS (EX–/E–), 30 wDDGS (EX–+/E–), 30 wDDGS (EX–+/E+), and 30 wDDGS (EX–+/E+).

**Experimental Birds and Management**

A total of 490 one-day old Hybrid Converter turkey hens (Lilydale Hatchery, Edmonton, AB T5C 1R9, Canada) were placed in battery cages at the University of Saskatchewan Poultry Centre. For the first 7 d, birds were kept in groups of 10 and had free access to a standard wheat soybean turkey starter crumbled diet (Co-op Feeds, Saskatoon, SK, Canada) providing 34.6% CP, 3,020 kcal/kg of AME, 0.66% methionine, 1.73% lysine, 1.49% calcium, and 0.76% available phos- phorus. On d 7, individually weighed turkey poult was wing banded and allocated into 2 experimental groups. Turkey poult were provided free access to feed and water. A standard brooding temperature starting from 32°C from 0 d and gradually reduced to 23°C at 21 d was used. The birds were exposed to 18L:6D (L:light, D:dark), with a light intensity of 10–20 lux.

**Experiment 1.** In experiment 1, 210 seven-day-old turkey poult were randomly assigned to 42 battery cages measuring 29.2 cm (height) × 48.3 cm (depth) × 83.8 cm (width; providing 1,010 cm3/bird at 21 d) in a completely randomized design. Poult were assigned to 6 different dietary treatments (described in Experiment 1 above), with a total of 5 birds per cage and 7 replicates per treatment.

On d 7, 14, and 21, body weight (BW) and feed intake (FI) were recorded. Gain:feed ratio was calcu- lated. For apparent metabolizable energy (AME) and nitrogen retention (NR) determination, excreta were collected 4 times between 19–21 d with plastic sheets laid on trays under the battery cages. Clean (free of feathers and feed) excreta samples were frozen (–20°C) until analyzed.

At the end of the trial (21 d) all 5 birds in each replic- ate cage were humanely killed by cervical dislocation and their digestive tract (gut) segments were removed. The weights of empty fat-free gut segments were removed. The weights of empty fat-free gut segments (i.e., fat removed around the gizzard) and proventriculus, and the lengths of the duodenum (intestinal segment directly associated with pancreas), jejunum (from distal duodenal loop to Meckel’s diverticulum), ileum (Meckel’s diverticulum to ileal-cecal junction), and total ceca were recorded. All weight and length measurements of the gut segments were expressed relative (%) to the body weight of the bird.

**Chemical Analysis**

The excreta samples collected in Experiments 1 and 2 were oven dried for 72 h at 55°C for moisture determina- tion. After drying, samples from each replicate were pooled together for analysis. Both diet and excreta was ground using a Retsch grinder with a 1.0 mm screen (ZM-100, Haan, Germany). All analyses were done in duplicate. Dry matter was determined by drying in a forced-air oven at 135°C for 2 h (AOAC, 1990). Crude protein (N × 6.25) was determined using a Lec- o enzyme (Model FP-528L, Leco Corp., St. Joseph, MI, USA), using EDTA as a standard. Celite585 (Acros Organic, Fisher Scientific, 112 Colonnade Road, Ottawa, Ontario), an acid insol- able ash marker (AIA), was analyzed using a modified procedure from Vogtmann et al. (1975). To measure AIA, 1–2 g of samples was weighed into 16 × 125 mm glass tubes (VWR North America, West Chester, PA, USA). The tubes were heated at 500°C for 24 h. The ash samples were then mixed with 5 mL of 4 N HCl and then oven heated for 1 h at 120°C. Samples were then cen- trifuged at 3,210 g for 10 min. The supernatants were carefully removed using a vacuum siphon and samples
washed twice with 5 mL water and then dried at 80°C overnight. These dried samples were further kilned at 500°C overnight.

Calculations

The following formulas by Scott and Hall (1998) were used for calculating apparent metabolizable energy (AME) and nitrogen retention (NR).

\[
\text{AME(kcal/kg of diet)} = \text{GE}_{\text{diet}} - \left(\text{GE}_{\text{excreta}} \times \left(\frac{\%\text{Marker}_{\text{diet}}}{\%\text{Marker}_{\text{excreta}}}\right)\right)
\]

\[
\text{NR} = 100 - \left[100 \times \left(\frac{\%\text{Marker}_{\text{diet}}}{\%\text{Marker}_{\text{excreta}}}\right) \times \left(\frac{\%\text{N}_{\text{excreta}}}{\%\text{N}_{\text{diet}}}\right)\right]
\]

Statistical Analysis

All experiments were analyzed using Proc GLM (General Linear Model) of SAS version 9.2 (SAS Institute Inc., 1996). A cage of 5 poults was considered an experimental unit. In Experiment 1, the data were analyzed as a 3 × 2 factorial arrangement. There were 3 levels of wDDGS (0, 15, and 30%) and 2 enzymes [none (E–), enzyme cocktail (E+)]. In Experiment 2, data were analyzed as a 2 × 2 × 2 factorial arrangement. There were 2 wDDGS levels (15 and 30%), 2 enzymes (E– and E+) and 2 processing methods (EX– and EX+). Means were considered statistically significant when \( P \leq 0.05 \). Duncan’s Multiple Range Test was used for separation of mean values when differences were significant.

RESULTS

The wDDGS used in the diet formulation contained 89.2% DM, 36.0% CP, 4.57% fat, and 6.29% crude fiber. Analyzed nutrient compositions of the respective dietary treatments (all experiments) are shown in Table 2. The overall health of turkey poults was excellent, and no poults were removed from the 2 studies. Overall, all treatments (Experiment 1 and 2) average 21 d BW was 675 ± 41.08 g, FI was 47.68 ± 3.58 g/d, and gain:feed was 0.768 ± 0.009. There was no interaction between main effects for intestinal measurements relative to BW; hence, only main effects are reported. To remove confounding effects of particles size, the wDDGS (EX–/EX+) were ground before feed mixing. Mean particle size (Dgw ± Sgw; data not shown) was higher for raw wDDGS (1330 ± 48.9 μm; unground); whereas the ground unextruded and extruded wDDGS (485 ± 41.96 μm; EX–, 415 ± 68.8 μm; EX+) used in the diets were not different.

### Table 2. Analyzed nutrient composition of dietary treatments fed to determine the effects extrusion of wheat DDGS (wDDGS1) with or without an enzyme cocktail2 (0.5 g/kg) on turkey hen poults (as fed).

<table>
<thead>
<tr>
<th>Item</th>
<th>Experiment 1</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry Matter (%)</td>
<td>AME3 (kcal/kg)</td>
<td>Crude protein (%)</td>
<td></td>
</tr>
<tr>
<td>0% E–</td>
<td>90.69</td>
<td>2786</td>
<td>29.57</td>
<td></td>
</tr>
<tr>
<td>0% E+</td>
<td>90.83</td>
<td>3124</td>
<td>29.54</td>
<td></td>
</tr>
<tr>
<td>15% E–</td>
<td>91.21</td>
<td>3086</td>
<td>29.13</td>
<td></td>
</tr>
<tr>
<td>15% E+</td>
<td>91.08</td>
<td>3211</td>
<td>29.63</td>
<td></td>
</tr>
<tr>
<td>30% E–</td>
<td>91.32</td>
<td>3260</td>
<td>30.04</td>
<td></td>
</tr>
<tr>
<td>30% E+</td>
<td>91.37</td>
<td>3299</td>
<td>29.35</td>
<td></td>
</tr>
</tbody>
</table>

1 wDDGS = wheat distillers dried grains with solubles.
2 Enzyme cocktail (Superzyme:100 units/g of xylanase, 375 units/g of glucoamylase, 350 units/g of invertase, 700 units/g of protease, 1650 units/g of cellulase, 7250 units/g of amylase, 230 unit/g of mannanase, and 25 unit/g of galactanase).
3 Apparent metabolizable energy.
4 No enzyme addition.
5 Enzyme addition.
6 No extrusion no enzyme.
7 No extrusion/enzyme.
8 Extrusion/no enzyme.
9 Extrusion/enzyme.

**Experiment 1: Effects of wheat distillers dried grains with solubles with or without an enzyme cocktail on performance and nutrient availability**

With the exception of the gain:feed (7–21 d), average BW (21 d), and FI (7–21 d; g/b/d) were higher for 0% wDDGS (Table 3). The inclusion levels of 15% and 30% wDDGS were not different from each other. The results indicate no effects of E; neither were there interactions between level of wDDGS inclusion and E on poul performance.

There were no interactions between inclusion level of wDDGS and enzyme for relative measurements of the intestinal tract segments. Proventriculus weight, gizzard weight, duodenal length, and ileal length were significantly higher for 30% wDDGS (Table 4). There was also the tendency (\( P = 0.06 \)) for jejunum length to be longer for birds fed diet containing 30% wDDGS. There was no effect of enzyme on gut segment size, with a numerical (\( P = 0.09 \)) increase in relative ileal length with enzyme cocktail supplementation.

Nitrogen retention and diet AME at 21 d are presented in Table 5. At 21 d, the NR was lower (\( P < 0.05 \)) for 0% wDDGS as compared to either 15 or 30%,
Table 3. Experiment 1. Effects of wheat distillers dried grains with solubles with or without an enzymes cocktail\(^1\) (0.5 g/kg) on the body weight, feed intake and gain:feed of turkey hen poults (7–21 d).

<table>
<thead>
<tr>
<th>Item</th>
<th>Body weight 7 d (g/b)</th>
<th>Body weight 21 d (g/b)</th>
<th>Feed intake (g/b/d)</th>
<th>Gain:feed (g/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels of wDDGS(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0% wDDGS</td>
<td>167</td>
<td>*</td>
<td>50.1(^a)</td>
<td>NS</td>
</tr>
<tr>
<td>15% wDDGS</td>
<td>168</td>
<td>681(^b)</td>
<td>47.6(^b)</td>
<td>0.769</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>168</td>
<td>664(^b)</td>
<td>46.7(^b)</td>
<td>0.758</td>
</tr>
<tr>
<td>Enzymes</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>None (E–)</td>
<td>168</td>
<td>688</td>
<td>48.6</td>
<td>0.764</td>
</tr>
<tr>
<td>Enzyme (E+)</td>
<td>168</td>
<td>677</td>
<td>47.6</td>
<td>0.764</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>2.4</td>
<td>12.7</td>
<td>1.01</td>
<td>0.0059</td>
</tr>
<tr>
<td>Source of variation</td>
<td>Probability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levels of wDDGS</td>
<td>NS</td>
<td>*</td>
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<td>NS</td>
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<tr>
<td>Enzymes</td>
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<td>NS</td>
<td>NS</td>
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<tr>
<td>Level of wDDGS +Enzyme</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Means with different superscripts within the same column are significantly different *\(P \leq 0.05\); **\(P \leq 0.01\).

\(^1\)Enzyme cocktail (Superzyme; 1,100 units/g of xylanase, 375 units/g of glucanase, 350 units/g of invertase, 700 units/g of protease, 1,650 units/g of cellulase, 7,250 units/g of amylase, 230 unit/g of mannanase and 25 units/g of galactanase).

\(^2\)wDDGS = Wheat distillers dried grains with solubles.

\(^3\)SEM = Standard error of means.

which were not different from each other. The NR was improved by enzyme supplementation. There was an interaction between wDDGS inclusion level and enzyme supplementation for NR determined at 21 d. The interaction indicates that enzymes increased NR of 0% wDDGS diets, but had no effect when 15 or 30% wDDGS were included. The AME determined at 21 d increased with each increase in wDDGS inclusion, and there was an overall improvement with enzyme supplementation. There was an interaction for AME at 21 d between wDDGS inclusion and enzyme supplementation. The interaction indicates that enzyme supplementation significantly improved the AME of diets with 0 or 15% wDDGS, but did not improve the AME in the 30% wDDGS diet.

Table 4. Experiment 1 Effects of wheat distillers dried grains with solubles with and/or without an enzyme cocktail\(^1\) (0.5 g/kg) on intestinal measurement relative to 21 d body weight.

<table>
<thead>
<tr>
<th>Item</th>
<th>Proventriculus weight (%)</th>
<th>Gizzard weight (%)</th>
<th>Duodenal length (%)</th>
<th>Duodenal length (%)</th>
<th>Jejunum length (%)</th>
<th>Jejunum weight (%)</th>
<th>Ileal length (%)</th>
<th>Ileal weight (%)</th>
<th>Caeca length (%)</th>
<th>Caeca weight (%)</th>
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</thead>
<tbody>
<tr>
<td>Levels of wDDGS(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0% wDDGS</td>
<td>0.445(^b)</td>
<td>2.26(^b)</td>
<td>2.86(^b)</td>
<td>0.919</td>
<td>6.84(^b)</td>
<td>1.62</td>
<td>6.89(^b)</td>
<td>1.18</td>
<td>4.30</td>
<td>0.746</td>
</tr>
<tr>
<td>15% wDDGS</td>
<td>0.454(^a)</td>
<td>2.24(^a)</td>
<td>3.09(^a)</td>
<td>0.886</td>
<td>7.27(^a)</td>
<td>1.54</td>
<td>7.11(^a)</td>
<td>1.16</td>
<td>4.35</td>
<td>0.856</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>0.476(^a)</td>
<td>2.40(^a)</td>
<td>3.13(^a)</td>
<td>0.913</td>
<td>7.36(^a)</td>
<td>1.58</td>
<td>7.44(^a)</td>
<td>1.16</td>
<td>4.40</td>
<td>0.694</td>
</tr>
<tr>
<td>Enzymes</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>None (E–)</td>
<td>0.465</td>
<td>2.33</td>
<td>2.97</td>
<td>0.903</td>
<td>7.06</td>
<td>1.59</td>
<td>6.99</td>
<td>1.17</td>
<td>4.39</td>
<td>0.750</td>
</tr>
<tr>
<td>Enzyme (E+)</td>
<td>0.452</td>
<td>2.27</td>
<td>3.09</td>
<td>0.909</td>
<td>7.26</td>
<td>1.57</td>
<td>7.30</td>
<td>1.16</td>
<td>4.31</td>
<td>0.781</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>0.0063</td>
<td>0.062</td>
<td>0.087</td>
<td>0.0537</td>
<td>0.132</td>
<td>0.063</td>
<td>0.221</td>
<td>0.043</td>
<td>0.154</td>
<td>0.132</td>
</tr>
<tr>
<td>Source of variation</td>
<td>Probability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levels of wDDGS</td>
<td>NS</td>
<td>*</td>
<td>**</td>
<td>NS</td>
<td>0.06</td>
<td>NS</td>
<td>NS</td>
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<tr>
<td>Enzymes</td>
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<td>NS</td>
<td>NS</td>
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<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

Means with different superscripts within the same column are significantly different *\(P \leq 0.05\); **\(P \leq 0.01\).

\(^1\)Enzyme cocktail (Superzyme; 1,100 units/g of xylanase, 375 units/g of glucanase, 350 units/g of invertase, 700 units/g of protease, 1,650 units/g of cellulase, 7,250 units/g of amylase, 230 unit/g of mannanase and 25 units/g of galactanase).

\(^2\)wDDGS = Wheat distillers dried grains with solubles.

\(^3\)SEM = Standard error of means.

Experiment 2: Effects of wheat distillers dried grains with solubles (with or without extrusion of wDDGS) and with or without an enzyme cocktail on performance and nutrient availability

The average performance (7–21 d) of turkey poults is shown in Table 6. There were no significant interactions (*\(P > 0.05\)) for performance variables. There was a significant effect (*\(P < 0.05\)) of inclusion level on 21 d BW and 7–21 d gain:feed; both were negatively affected by 30% as compared to 15% wDDGS inclusion. There was no effect of inclusion level on FI. There were no effects of enzyme or extrusion of wDDGS used in the diets on BW, FI, or gain:feed.
Table 5. Experiment 1. Effects of wheat distillers dried grains with solubles with and/or without an enzyme cocktail\(^1\) (0.5 g/kg) on 21 d nitrogen retention and apparent metabolizable energy of turkey hen poults.

<table>
<thead>
<tr>
<th>Item</th>
<th>Nitrogen retention (%)</th>
<th>AME (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels of wDDGS</td>
<td>Enzymes</td>
<td></td>
</tr>
<tr>
<td>0% wDDGS(^2)</td>
<td>None (E–)</td>
<td>47.5(^{b})</td>
</tr>
<tr>
<td>0% wDDGS</td>
<td>Enzyme (E+)</td>
<td>57.8(^{a})</td>
</tr>
<tr>
<td>15% wDDGS</td>
<td>None (E–)</td>
<td>56.2(^{a})</td>
</tr>
<tr>
<td>15% wDDGS</td>
<td>Enzyme (E+)</td>
<td>58.4(^{a})</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>None (E–)</td>
<td>58.0(^{a})</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>Enzyme (E+)</td>
<td>58.7(^{a})</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td></td>
<td>0.87</td>
</tr>
</tbody>
</table>

Source of variation | Probability | |
| Levels of wDDGS | ** | ** |
| Enzymes | ** | ** |
| Level of wDDGS × Enzyme | ** | ** |

Means with different superscripts within the same column are significantly different \( ^{*}P \leq 0.05; \ **^{*}P \leq 0.01 \).

\(^{1}\) Enzyme cocktail (Superzyme; 1100 units/g of xylanase, 375 units/g of glucanase, 350 units/g of invertase, 700 units/g of protease, 1650 units/g of cellulase, 7250 units/g of amylase, 230 unit/g of mannanase and 25 units/g of galactanase).

\(^{2}\) wDDGS = Wheat distillers dried grains with solubles.

\(^{3}\) SEM = Standard error of means.

Table 6. Experiment 2. Effects of wheat distillers dried grains with solubles with and/or without an enzyme cocktail\(^1\) (0.5 g/kg) with and/or without extrusion process on mean body weight (BW), feed intake (FI) and gain:feed of turkey hen poults (7–21 d).

<table>
<thead>
<tr>
<th>Item</th>
<th>Body weight 7 d (g/b)</th>
<th>Body weight 21 d (g/b)</th>
<th>Feed intake (g/b/d)</th>
<th>Gain:feed (g/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels of DDGS(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15% wDDGS</td>
<td>167</td>
<td>681(^{a})</td>
<td>47.7</td>
<td>0.769(^{a})</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>168</td>
<td>657(^{b})</td>
<td>46.5</td>
<td>0.751(^{b})</td>
</tr>
<tr>
<td>Enzymes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None (E–)</td>
<td>167</td>
<td>674</td>
<td>47.7</td>
<td>0.757</td>
</tr>
<tr>
<td>Enzyme (E+)</td>
<td>168</td>
<td>664</td>
<td>46.5</td>
<td>0.763</td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-extruded (EX–)</td>
<td>168</td>
<td>673</td>
<td>47.2</td>
<td>0.764</td>
</tr>
<tr>
<td>Extruded (EX+)</td>
<td>167</td>
<td>665</td>
<td>47.0</td>
<td>0.756</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>15.4</td>
<td>1.39</td>
<td>0.0110</td>
<td></td>
</tr>
</tbody>
</table>

Source of variation | Probability | |
| Levels of DDGS | NS | * |
| Enzymes | NS | NS | NS | NS |
| Processing | NS | NS | NS | NS |

*, NS Indicates Significance at \( P \leq 0.05 \) and not significant respectively.

Means with different superscripts within the same column are significantly different \( ^{*}P \leq 0.05; \ **^{*}P \leq 0.01 \).

\(^{1}\) Enzyme cocktail (Superzyme; 1100 units/g of xylanase, 375 units/g of glucanase, 350 units/g of invertase, 700 units/g of protease, 1650 units/g of cellulase, 7250 units/g of amylase, 230 unit/g of mannanase and 25 units/g of galactanase).

\(^{2}\) wDDGS = Wheat distillers dried grains with solubles.

\(^{3}\) SEM = Standard error of means.

There were no interactions between inclusion level (15 or 30%) of wDDGS, extrusion, or enzyme supplementation for relative gut segment size estimates (Table 7). The only effect of wDDGS inclusion level was an increase in relative proventriculus weight and ileal length with increased wDDGS. Enzyme supplementation decreased relative proventriculus and gizzard weight and had a numerical effect of increasing relative duodenal \( (P = 0.07) \) and caecal \( (P = 0.09) \) length. The extrusion of wDDGS in the diets reduced both relative proventriculus and gizzard weights, but had no effect on the measurements for the other gut segments.

At 21 d there was no effect of inclusion level on NR (Table 8) but there was a positive response to 30% as compared to 15% wDDGS inclusion on AME (21 d). The results indicated no effect of enzyme. There was a tendency \( (P = 0.10) \) of improvement in NR for diets with extruded wDDGS and this was significant for AME. There were 2-way (enzyme × extrusion) and 3-way (inclusion level of wDDGS × enzyme × extrusion) interactions for 21 d NR and AME. For NR, the 3-way interaction signifies that for 15% wDDGS inclusion there was no effect of enzyme when wDDGS were not extruded and a negative effect when wDDGS was extruded. At 30% inclusion there was no effects of enzyme...
Table 7. Experiment 2. Effects of wheat distillers dried grains with solubles with and/or without an enzyme cocktail (0.5 g/kg) with and/or without extrusion on intestinal measurement relative to 21d body weight. There were no significant 2-way or 3-way interactions.

<table>
<thead>
<tr>
<th>Item</th>
<th>Proventriculus weight (%)</th>
<th>Gizzard weight (%)</th>
<th>Duodenal length (%)</th>
<th>Duodenal weight (%)</th>
<th>Jejunum length (%)</th>
<th>Jejunum weight (%)</th>
<th>Ileal length (%)</th>
<th>Ileal weight (%)</th>
<th>Caeca length (%)</th>
<th>Caeca weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels of wDDGS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15% wDDGS</td>
<td>0.449&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.23</td>
<td>3.16</td>
<td>0.911</td>
<td>7.24</td>
<td>1.52</td>
<td>7.09b</td>
<td>1.15</td>
<td>4.45</td>
<td>0.797</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>0.464&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.30</td>
<td>3.18</td>
<td>0.923</td>
<td>7.38</td>
<td>1.54</td>
<td>7.48a</td>
<td>1.18</td>
<td>4.51</td>
<td>0.699</td>
</tr>
<tr>
<td>Enzymes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None (E–)</td>
<td>0.465&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.11</td>
<td>0.900</td>
<td>7.32</td>
<td>1.56</td>
<td>7.27</td>
<td>1.16</td>
<td>4.37</td>
<td>0.776</td>
</tr>
<tr>
<td>Enzyme (E+)</td>
<td>0.449&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.21&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.24</td>
<td>0.935</td>
<td>7.30</td>
<td>1.50</td>
<td>7.30</td>
<td>1.17</td>
<td>4.58</td>
<td>0.721</td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-extruded (EX–)</td>
<td>0.465&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.17</td>
<td>0.945</td>
<td>7.34</td>
<td>1.52</td>
<td>7.25</td>
<td>1.17</td>
<td>4.49</td>
<td>0.737</td>
</tr>
<tr>
<td>Extruded (EX+)</td>
<td>0.449&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.17</td>
<td>0.889</td>
<td>7.27</td>
<td>1.54</td>
<td>7.33</td>
<td>1.16</td>
<td>4.48</td>
<td>0.758</td>
</tr>
<tr>
<td>Pooled SEM</td>
<td>0.0102</td>
<td>0.060</td>
<td>0.097</td>
<td>0.0585</td>
<td>0.207</td>
<td>0.063</td>
<td>0.215</td>
<td>0.045</td>
<td>0.172</td>
<td>0.1156</td>
</tr>
<tr>
<td>Source of variation</td>
<td>Probability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levels of wDDGS</td>
<td>*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Processing</td>
<td>*</td>
<td>*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

SEM = Standard error of means.

Means with different superscripts within the same column are significantly different *P ≤ 0.05.

wDDGS = Wheat distillers dried grains with solubles.

Enzyme cocktail (Superzyme;1,100 units/g of xylanase, 375 units/g of glucanase, 350 units/g of invertase, 700 units/g of protease, 1,650 units/g of cellulase, 7,250 units/g of amylase, 230 unit/g of mannanase, and 25 units/g of galactanase.

Table 8. Experiment 2. Effects of wheat distillers dried grains with solubles with or without an enzyme cocktail<sup>1</sup> (0.5 g/kg) with and/or without extrusion on 21 d diet nitrogen retention and apparent metabolizable energy of turkey hen poults.

<table>
<thead>
<tr>
<th>Item</th>
<th>Nitrogen retention (%)</th>
<th>AME (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of wDDGS</td>
<td>Enzyme</td>
<td>Processing</td>
</tr>
<tr>
<td>15% wDDGS&lt;sup&gt;2&lt;/sup&gt;</td>
<td>None (E–)</td>
<td>Non-extruded (EX–)</td>
</tr>
<tr>
<td>15% wDDGS</td>
<td>None (E–)</td>
<td>Extruded (EX+)</td>
</tr>
<tr>
<td>15% wDDGS</td>
<td>Enzyme (E+)</td>
<td>Non-extruded (EX–)</td>
</tr>
<tr>
<td>15% wDDGS</td>
<td>Enzyme (E+)</td>
<td>Extruded (EX+)</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>None (E–)</td>
<td>Non-extruded (EX–)</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>None (E–)</td>
<td>Extruded (EX+)</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>Enzyme (E+)</td>
<td>Non-extruded (EX–)</td>
</tr>
<tr>
<td>30% wDDGS</td>
<td>Enzyme (E+)</td>
<td>Extruded (EX+)</td>
</tr>
<tr>
<td>Pooled SEM&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source of variation</td>
<td>Probability</td>
<td></td>
</tr>
</tbody>
</table>

Means with different superscripts within the same column are significantly different *P ≤ 0.05; **P ≤ 0.01.

<sup>1</sup>Enzyme cocktail (Superzyme;1100 units/g of xylanase, 375 units/g of glucanase, 350 units/g of invertase, 700 units/g of protease, 1650 units/g of cellulase, 7250 units/g of amylase, 230 unit/g of mannanase, and 25 units/g of galactanase).

<sup>2</sup>Enzyme cocktail (Superzyme;1,100 units/g of xylanase, 375 units/g of glucanase, 350 units/g of invertase, 700 units/g of protease, 1,650 units/g of cellulase, 7,250 units/g of amylase, 230 unit/g of mannanase, and 25 units/g of galactanase);

<sup>3</sup>SEM = Standard error of means.

or extrusion on NR. The 3-way interaction for AME indicates that at 15% inclusion there was a positive effect of enzyme with no extrusion, whereas there was a negative effect of enzyme with extrusion. For the 30% wDDGS inclusion there were no effects of diet whether the wDDGS were extruded or not.

**DISCUSSION**

Generally, due to depression in performance associated with feeding diets high in fiber; feeding higher levels of wDDGS to poultry is of concern (Lee et al., 2003). The present study evaluates the potential for processing with or without enzyme supplementation on feed nutrient intake and nutrient utilization of diets containing up to 30% wDDGS. The results indicate significantly lower performance by feeding up to 30% wDDGS but birds remained healthy throughout the experiment. This is consistent with the findings of Roberson (2003), Wang et al. (2007), and Abdel-Raheem et al. (2011). Monogastrics lack the enzymes necessary to breakdown the complex cell wall structure of fiber; hence a
reduction in performance was not surprising. Bach Knudsen (2001) has reported that higher intake of dietary fiber decreases the total tract energy digestibility, which results in an increase percentage of energy being digested in the large intestines. Consequently this results in less monosaccharide absorption in the small intestines (Bach Knudsen, 2001; Svilhus et al., 2013). According to Bach Knudsen (2001), about 1% energy digestion in the large intestines results in a decrease in the utilization of metabolizable energy (∼0.27%). Additionally, increasing heat treatments during processing may result in increasing levels of soluble NSPs that are associated with higher digesta viscosity and, consequently, poor nutrient utilization.

On the other hand, during ethanol production, most starch in the cereal is converted to ethanol (Kerr and Shurson, 2013). The extraction of fat is also commonly practiced in modern ethanol plants using corn as a substrate (Wisner et al., 2013); however, this is not practiced when wheat is used as a substrate. These practices can significantly reduce the energy content of the co-product. The lower performance with diets containing 30% wDDGS in the present study contradicts our earlier findings (Opoku et al., 2012). However, the wDDGS used in both studies were sourced from the same processing facility. It is critical to understand that processes involved in the production of DDGS are variable within and between processing plants. There is evidence of variability in nutrient level and digestibility in wDDGS obtained from the same plant in Western Canada (Lumpkins et al., 2004; Oryschak et al., 2010b). With the inconsistencies in DDGS, the assumed nutritional composition is often inaccurate (Liu, 2012), thus leading to errors in feed formulations.

The use of carbohydrase enzyme or a multi-enzyme complex is intended to release sugars from fibrous carbohydrates for higher absorption and assimilation in the small intestines (Meng and Slominski, 2005; Emiola et al., 2009; and Ziemer et al., 2012). Nonetheless a multi-enzyme supplementation was not effective on performance when feeding higher levels of wDDGS. This effect was also observed in our previous study (Opoku et al., 2012); although this study compared individual supplementation of protease and/or β-mannanase. Omogbemignun et al. (2004) on the other hand, showed improved performance when an enzyme cocktail (cellulase, galactanase, mannanase, and pectinase) was supplemented in wheat-based diets fed to pigs. Omogbemignun et al. (2004) attributed this to an improvement in ileal fiber digestibility that improves overall nutrient absorption and minimizes lower tract fermentation and loss of nutrients.

Nutrient digestibility (21 d) was, in some instances, higher for 30% wDDGS. This is similar to that reported by Oryschak et al. (2010a) and Opoku et al. (2012). The higher fiber might have resulted in slower transit time of digesta and better interaction of endogenous enzymes with digesta in the gut and thereby improved digestibility (Lee et al., 2003). However, the lack of a direct link between improvements in digestibility and performance are confusing, but have been reported previously (Opoku et al., 2012) and may be associated with overall limitations in nutrient intake.

Beneficial interactions among carbohydrases (Choct et al., 2004; Tahir et al., 2008) have been reported. Similarly, Inborr et al. (1993) and Olukosi et al. (2010) reported an increase nutrient digestibility in broilers and pigs when a multi-enzyme complex containing a combination of xylanase, amylase, protease or β-glucanase, xylanase, and amylase was used. The interaction between inclusion level and enzyme for 21 d NR levels in Experiment 1 could be related to differences in the diet ingredient matrix. This may explain why enzymes were more effective at lower levels as compared to higher inclusion levels of wDDGS. The increased AME for 0 and 15% due to interaction with enzyme supplemented suggests that cocktail enzyme is probably more efficient; but this could depend on the percentage of less digestible ingredient in the diet included.

Enzyme supplementation according to Choct et al. (1996) directs most of the fiber degradation in the gut towards the caeca instead of the lower digestive tract. With its fermentation capability, the caeca is a source of volatile fatty acid (VFA) production in birds (Svilhus et al., 2013). The numerically (P = 0.09; 4.59%) increased relative caeca length (Experiment 2) due to enzyme supplementation compared to diets fed without enzymes might signify an increase in fiber fermentation. Svilhus et al. (2013) indicated that the VFA production would result in an increase in energy digestibility. However, no improvement in energy digestibility was found with enzyme supplementation in Experiment 2. We did not measure VFA production in the present study.

To our knowledge this experiment is the first to report the impact of extrusion on wDDGS fed to turkey hens. Extrusion did not positively affect the performance of turkey pouls in the present study. Amornthewaphat et al. (2005) reported a significant improvement in performance when broilers were fed extruded corn. Gracia et al. (2003) showed that steam cooking at 99 ± 2°C of barley base diet to chicks improved performance until 8 d of age, but the effect disappeared thereafter. Additionally, Vukic-Vranjes et al. (1994) observed a negative effect on average daily gain and feed conversion ratio in 21 d broilers fed wheat and corn extruded diets. The reason for the inconsistencies among available data might be related to the ingredients, the conditions (time, temperature and/or moisture) applied for extrusion and the age of the birds (Gonzalez-Alvarado et al. 2007; Gracia et al., 2009). Application of heat solubilizes the fibrous component of ingredient (Garcia et al., 2008; DeVries et al., 2012), which increases the solubility of dietary fiber resulting in increased intestinal viscosity (Mateos et al., 2002; Gracia et al., 2003; Scott et al., 2003). Apparently, this may impair effective nutrient utilization in turkey hen pouls.
Unfortunately, we do not have data on intestinal viscosity in the present study.

Hydrothermal treatments modify the physicochemical structure of the diet, including the fiber component (Bjorck and Asp, 1983), and pathogens in feed ingredients and facilitate the accessibility of enzymes thereby improving their digestibility (Oryschak et al., 2010a, b) reported an increase in apparent ileal digestibility of amino acids by single screw (triticale DDGS) and twin screw extrusion (wheat and corn DDGS), in their respective studies. The improvement in 21 d digestibility may signify beneficial effects with extruded wDDGS in the diets. It is surprising as to why the improvement in nutrient digestibility with extruded diets was not mirrored in improved performance.

Gracia et al. (2003) reported an increase in nutrient digestibility when a steam-cooked barley-based diet was supplemented with an enzyme complex containing xylanase, protease, and amylase. Similarly, Vukic-Vranjes and Wenk (1995) indicated a significant positive effect in an enzyme supplemented extruded barley-based diet on AMEn of broilers. The present study recorded no significant impact of enzyme supplementation on extruded wDDGS. The use of hemicellulase enzymes (Smith et al., 2006) with a combined effect of processing during ethanol production should have resulted in hydrolyzing NSPs. Detailed information on the composition of the fiber-fraction and digestibility of its components would assist in identifying and understanding the modifications that occur during processing (deVries et al., 2012).

In summary, the current studies show that wDDGS is a potential energy and protein source for turkeys. However, with the high fiber content of this feedstuff, more studies should be conducted to gain a better understanding of how the high fiber content might influence the feed value of wDDGS for young turkeys. It would seem futile to continue the application of enzymes to wDDGS if detailed analysis is not done to determine the major fiber fractions and subsequently the appropriate cocktail of enzyme combination and levels to be used. These experiments have illustrated some beneficial effects of processing (extrusion) with or without an enzyme cocktail supplementation on nutrient digestibility but no improvement in performance were observed. Outside the bounds of this study, it would be interesting if future research investigates the potential of altering processing variables during wDDGS extrusion.

ACKNOWLEDGMENTS

The authors note the support of the Turkey Producers of Saskatchewan, the Canadian Poultry Research Council, and NSERC CRD. We acknowledge the support of Canadian Bio-System, Calgary, Alberta for provision of the enzymes and the Saskatchewan Food Industry Development Centre Inc. for the extrusion process. We are grateful to the staff of the University of Saskatchewan Poultry Centre for their assistance in carrying out these trials.

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