Effects of corn source on the relationship between in vitro assays and ileal nutrient digestibility

C. K. Gehring,* M. R. Bedford,† A. J. Cowieson,‡ and W. A. Dozier III*‡

*Department of Poultry Science, Auburn University, Auburn, AL 36849; †AB Vista Feed Ingredients, Marlborough, Wiltshire, SN8 4AN, United Kingdom; and ‡Poultry Research Foundation, The Faculty of Veterinary Science, University of Sydney, Camden, New South Wales 2570, Australia

ABSTRACT An experiment was conducted to determine the relationship between in vitro assays to estimate quality and ileal nutrient and energy digestibility of various corn sources. Twelve samples of corn were analyzed for gross energy (GE), N, moisture, crude fat (CF), salt-soluble protein content (SSP), and vitreousness. Six of the 12 sources of corn had similar proximate composition but ranged in pairs as having low, moderate, or high quality based on protein solubility that varied from 25.7 to 49.2%. Experimental diets consisted of corn sources with 0.50% TiO2. In total, 504 (12 per pen; 0.039 m2 per bird) Ross × Ross 708 male broiler chicks were randomly distributed to 42 pens (7 replicates per treatment) at 1 d of age. Broilers were fed common starter and grower diets from 1 to 27 d of age and experimental diets from 28 to 30 d of age. At 30 d of age, 8 birds per cage were euthanized for digesta collection from 4 to 30 cm proximal to the ileocelecal junction. Feed and digesta were analyzed for TiO2, GE, N, CF, and starch content. Ileal digestibility of N (apparent), CF, and starch did not differ (P > 0.05) among sources of corn. Apparent ileal digestible energy (IDE) of the 6 corns averaged 3,323 kcal/kg. Salt-soluble protein concentration was correlated with IDE among the corns (r = 0.5; P < 0.001). Ileal N and fat digestibility were correlated with IDE (r = 0.4 and 0.3, respectively; P < 0.05). Apparent MEr ranged from 3,262 to 3,342 kcal/kg and was correlated with SSP (r = 0.8; P < 0.001) and IDE (r = 0.36; P < 0.05). These results indicated that sources of corn with similar proximate composition may vary in their digestible energy content, and in such a situation, SSP may be used to differentiate those with wide-ranging IDE or AMEn. However, further research is required to investigate the relationship between SSP and growth performance of broilers.

Key words: broiler, screening method, ingredient quality, ileal nutrient digestibility

INTRODUCTION

Variation in nutrient content of corn has the potential to greatly affect the profitability of broiler production. For example, variation in AMEn may translate to economically important changes in feed conversion (Dozier et al., 2011). To prevent unforeseen reductions in growth performance, grading and analytical methods are used to minimize nutrient variability between calculated and analyzed values. In the present grading system, corn is graded based on bushel weight, damaged kernels, and foreign material (USDA, 2004) even though other factors may affect its feeding value (Sommers, 2001). Differences between corn samples can yield variability in AMEn of more than 400 kcal/kg (Cowieson, 2005). Grading methods used to evaluate corn, such as bushel weight, may be poor estimators of feeding value (Leeson et al., 1993; Dale, 1994), potentially ignoring inherent variation in nutrient content and digestibility. Furthermore, the USDA corn grading system is based primarily on physical characteristics and it may be useful to evaluate feed ingredients based on chemical attributes which may vary independently of proximate composition or appearance.

Nutrient digestibility of corn is affected by agronomic conditions, genetics, postharvest processing, storage conditions, and antinutritional factors (Cowieson, 2005). However, corn is priced with disregard to variations in chemical quality due to the vast scale of analysis that would be required commercially (Moore et al., 2008) and the acceptance that nutrient value of feed ingredients may be constant based on broad-based quality designations (de Coca-Sinova et al., 2008). Assays have been developed to improve identification of
corn quality, such as salt-soluble protein content (SSP) and vitreousness (Dombrink-Kurtzman and Bietz, 1993). These assays may identify differences in feeding quality unaccounted for under the current grading system. Salt-soluble protein and vitreousness assays may provide a means to assess differences in protein and starch accessibility related to the starch-protein interface, which should affect subsequent digestibility.

To our knowledge, there is a lack of peer-reviewed information regarding the combination of these techniques to predict nutrient digestibility of diverse samples of corn in broilers. The objective of this research was to evaluate the relationship between various analytical assays to predict quality of United States corn samples and ileal nutrient digestibility in broilers. Twelve sources of corn were analyzed for proximate composition, and quality was evaluated based on SSP and vitreousness. Six of the 12 sources of corn that had similar proximate composition but varied in predicted quality were fed to 28-d-old broilers and ileal nutrient digestibility in broilers. Twelve samples of corn originating from the Midwest and southeast United States were analyzed for DM (method 930.15; AOAC, 2006), gross energy (GE), N, and crude fat (CF; Table 1). Gross energy was determined using an isoperibol bomb calorimeter (model number 6300, Parr Instruments, Moline, IL) as described by the manufacturer’s manual (Parr Instruments, 1948). Nitrogen content was determined via the Dumas method (method 990.03; AOAC, 2006) using a N analyzer (Rapid N Cube, Elementar Analysensysteme GmbH, Hanau, Germany) and crude protein was calculated by multiplying percent N by a correction factor (6.25). Crude fat was determined by submerging samples in boiling hexane (method 2003.06; AOAC, 2006) in a fat extractor (Soxtect model number 2043, Foss Westfalia, Huntville, AL) were obtained from a commercial hatchery and randomly distributed to 42 battery cages (7 replicates per treatment) in a solid-sided facility at 1 d of age. Broilers were vaccinated for Marek’s disease.

**MATERIALS AND METHODS**

**Compositional and Quality Analysis**

Twelve samples of corn originating from the Midwest and southeast United States were analyzed for DM (method 930.15; AOAC, 2006), gross energy (GE), N, and crude fat (CF; Table 1). Gross energy was determined using an isoperibol bomb calorimeter (model number 6300, Parr Instruments, Moline, IL) as described by the manufacturer’s manual (Parr Instruments, 1948). Nitrogen content was determined via the Dumas method (method 990.03; AOAC, 2006) using a N analyzer (Rapid N Cube, Elementar Analysensysteme GmbH, Hanau, Germany) and crude protein was calculated by multiplying percent N by a correction factor (6.25). Crude fat was determined by submerging samples in boiling hexane (method 2003.06; AOAC, 2006) in a fat extractor (Soxtect model number 2043, Foss Westfalia, Huntville, AL) were obtained from a commercial hatchery and randomly distributed to 42 battery cages (7 replicates per treatment) in a solid-sided facility at 1 d of age. Broilers were vaccinated for Marek’s disease.

**Experimental Treatments**

Corn sources that had similar proximate composition but that differed based on values obtained from various analytical procedures were selected to provide the widest range of potential feeding quality. The 6 sources of corn evaluated for apparent ileal energy and nutrient digestibility were selected primarily based on differences in SSP because vitreousness was similar among all corn sources (Table 3). Corn sources that were selected varied widely in SSP to provide 2 each of 3 quality designations (low, moderate, and high). Mean values of SSP and vitreousness of the selected corns ranged from 25.7 to 49.2% and 57.8 to 59.8%, respectively.

**Broiler Husbandry**

All procedures relating to the use of live birds were approved by the Auburn University Institutional Animal Care and Use Committee (PRN 2010–1717). Five hundred and four (12 per cage; 0.039 m² per bird) Ross × Ross 708 male broiler chicks (Aviagen North America, Huntsville, AL) were obtained from a commercial hatchery and randomly distributed to 42 battery cages (7 replicates per treatment) in a solid-sided facility at 1 d of age. Broilers were vaccinated for Marek’s disease.

**Table 1. Proximate composition of dent corn obtained from the United States¹,²,³**

<table>
<thead>
<tr>
<th>Sample</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>13.6</td>
<td>13.2</td>
<td>14.0</td>
<td>13.1</td>
<td>11.4</td>
<td>13.3</td>
<td>13.0</td>
<td>12.5</td>
<td>13.4</td>
<td>13.4</td>
<td>11.9</td>
<td>13.5</td>
</tr>
<tr>
<td>Gross energy (kcal/kg)</td>
<td>3,863</td>
<td>3,865</td>
<td>3,903</td>
<td>3,914</td>
<td>3,890</td>
<td>3,916</td>
<td>3,897</td>
<td>3,924</td>
<td>3,883</td>
<td>3,891</td>
<td>3,891</td>
<td>3,901</td>
</tr>
<tr>
<td>CP²</td>
<td>7.33</td>
<td>8.87</td>
<td>6.88</td>
<td>7.56</td>
<td>8.91</td>
<td>7.55</td>
<td>6.77</td>
<td>7.21</td>
<td>7.81</td>
<td>7.27</td>
<td>8.05</td>
<td>8.22</td>
</tr>
<tr>
<td>Crude fat (g/kg)</td>
<td>3.02</td>
<td>2.74</td>
<td>3.29</td>
<td>3.41</td>
<td>3.03</td>
<td>3.44</td>
<td>3.23</td>
<td>3.33</td>
<td>3.00</td>
<td>3.32</td>
<td>2.96</td>
<td>3.08</td>
</tr>
</tbody>
</table>

¹Values for gross energy, crude protein, and crude fat are expressed on an 88% DM (as-fed) basis.
²Analyses were performed on duplicate samples.
³Summary statistics (mean, coefficient of variation): moisture (13.0, 5.7), DM (87.0, 0.9), gross energy (3,895, 0.5), CP (7.7, 9.1), crude fat (3.15, 6.8).
⁴6.25 × % N.
ease, infectious bronchitis, and Newcastle disease at the hatchery. From 1 to 27 d of age, all birds were provided common corn-soybean meal-based diets formulated with a single source of corn (0 to 17 d of age = AMEn, 3,075 kcal/kg; digestible Lys, 1.22%; digestible TSAA, 0.92%; digestible Thr, 0.83%; Ca, 0.90%; and nonphytate P, 0.45%; 18 to 27 d of age = AMEn, 3,140 kcal/kg; digestible Lys, 1.13%; digestible TSAA, 0.86%; digestible Thr, 0.74%, Ca, 0.80%; and nonphytate P, 0.40%) and reared with identical management practices until 27 d of age. The ambient temperature set point was 33°C at placement and was decreased as the birds increased in age, with a final set point of 24°C at 30 d of age. Photoperiod was 23 h of light and 1 h of darkness from 1 to 23 d of age and a 12-h L:D cycle from 24 to 30 d of age.

**Nutrient Digestibility Assay**

Each of the 6 sources of corn was ground through a hammer mill fitted with a 3-mm screen. Broilers were fed the experimental diets (corn mixed with 0.5% TiO2 added as an inert marker) for 72 h (28 to 30 d of age), according to Leslie et al. (2007). Corn was fed ad is without supplemental vitamins or minerals. The duration of the experiment was assumed to permit interpretation of digestibility data free from confounding by potential nutritional deficiencies (Sullivan et al., 1974), as described by Leslie et al. (2007). Birds weighed >1.3 kg at the start of the experimental period and consumed approximately 100 g of corn/bird/day. At 30 d of age, 8 birds per experimental unit were euthanized by CO2 inhalation. The digesta contents of the terminal ileum [a section spanning 4 to 30 cm upstream from the ileocecal junction (Rochelle et al., 2012)] were gently flushed with deionized water into sample cups and stored at −20°C until further analysis. From 29 to 30 d of age, feed intake was determined and all excreta were collected for determination of AMEn (Sibbald, 1979). Feed, digesta, and excreta were lyophilized in a Virtis Genesis Pilot Lyophilizer (SP Industries, Warminster, PA) and ground using a cyclone mill (Cyclocut model number 1093, Foss North America Inc., Eden Prairie, MN; feed and excreta) or an electric coffee grinder (digesta). At 30 d of age, broilers yield approximately 1 g of dry digesta from the terminal ileum, and a coffee grinder was used to provide finely ground sample without significant loss.

Feed and digesta from each experiment were analyzed for TiO2 by a method based on that of Leone et al. (1973). Briefly, 0.25 g of sample were added to glass test tubes and ashed at 580°C for 10 h; ashed samples diluted with 5 mL of H2SO4 and containing 0.8 g of NaSO4 were heated at 130°C for 72 h; contents of each tube were diluted to 50 mL with distilled deionized water and held for 12 h at 25°C; 3 mL of feed samples or 1 mL of digesta samples (with 2 mL of 1.8 M H2SO4) were added to glass test tubes with 150 μL of H2O2; and after color development (30 min), absorbance was measured on a spectrophotometer at 410 nm. Feed was also analyzed for GE, N, CF, and starch content, and excreta were analyzed for N and GE content. Titanium dioxide content in feed samples was analyzed in quadruplicate, and excreta were analyzed for N and GE content. Titanium dioxide content in feed samples was analyzed in quadruplicate, and excreta were analyzed for N and GE content.

### Table 2. In vitro predictors of quality and nutrient composition of corn selected to vary in salt-soluble protein content and to have similar proximate composition1,2

<table>
<thead>
<tr>
<th>Sample</th>
<th>SSP4 (%</th>
<th>Vitreousness</th>
<th>Starch (%)</th>
<th>CP (%)</th>
<th>Crude fat (%)</th>
<th>Crude fiber (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8–High</td>
<td>49.2</td>
<td>58.5</td>
<td>65.9</td>
<td>7.36</td>
<td>3.27</td>
<td>2.35</td>
</tr>
<tr>
<td>2–High</td>
<td>46.6</td>
<td>59.8</td>
<td>65.7</td>
<td>8.72</td>
<td>3.04</td>
<td>2.46</td>
</tr>
<tr>
<td>10–Moderate</td>
<td>39.4</td>
<td>59.2</td>
<td>66.5</td>
<td>7.15</td>
<td>3.27</td>
<td>2.31</td>
</tr>
<tr>
<td>7–Moderate</td>
<td>33.4</td>
<td>59.7</td>
<td>65.6</td>
<td>7.19</td>
<td>3.34</td>
<td>2.33</td>
</tr>
<tr>
<td>1–Low</td>
<td>26.9</td>
<td>60.0</td>
<td>65.9</td>
<td>7.19</td>
<td>3.27</td>
<td>2.28</td>
</tr>
<tr>
<td>3–Low</td>
<td>25.7</td>
<td>57.8</td>
<td>66.8</td>
<td>7.05</td>
<td>3.25</td>
<td>2.27</td>
</tr>
</tbody>
</table>

1 Analyses were performed on duplicate samples.
2 Values for starch, CP, crude fat, and crude fiber content are expressed on an 88% DM (as-fed) basis.
3 Sample number corresponds with Table 1 and high, moderate, and low terms are indicative of salt-soluble protein content.
4 Salt-soluble protein content.

### Table 3. Particle size distribution of corn selected to vary in salt-soluble protein content and to have similar proximate composition1

<table>
<thead>
<tr>
<th>Sample2</th>
<th>Mean particle size</th>
<th>3,360 μm³ (%)</th>
<th>2,380 μm (%)</th>
<th>1,680 μm (%)</th>
<th>1,191 μm (%)</th>
<th>841 μm (%)</th>
<th>594 μm (%)</th>
<th>420 μm (%)</th>
<th>297 μm (%)</th>
<th>212 μm (%)</th>
<th>150 μm (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8–High</td>
<td>975 ± 1.6</td>
<td>0.5</td>
<td>1.7</td>
<td>5.9</td>
<td>15.5</td>
<td>58.9</td>
<td>4.8</td>
<td>5.1</td>
<td>4.9</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>2–High</td>
<td>954 ± 1.6</td>
<td>0.4</td>
<td>1.0</td>
<td>6.1</td>
<td>18.0</td>
<td>55.4</td>
<td>4.0</td>
<td>5.4</td>
<td>6.8</td>
<td>2.1</td>
<td>0.4</td>
</tr>
<tr>
<td>10–Moderate</td>
<td>925 ± 1.7</td>
<td>0.3</td>
<td>1.4</td>
<td>6.7</td>
<td>17.4</td>
<td>51.9</td>
<td>4.8</td>
<td>4.8</td>
<td>8.2</td>
<td>2.6</td>
<td>0.3</td>
</tr>
<tr>
<td>7–Moderate</td>
<td>989 ± 1.6</td>
<td>0.7</td>
<td>1.6</td>
<td>6.1</td>
<td>15.8</td>
<td>59.6</td>
<td>4.7</td>
<td>4.7</td>
<td>4.3</td>
<td>1.3</td>
<td>0.7</td>
</tr>
<tr>
<td>1–Low</td>
<td>1,000 ± 1.7</td>
<td>1.5</td>
<td>2.5</td>
<td>8.1</td>
<td>18.3</td>
<td>51.5</td>
<td>3.6</td>
<td>5.5</td>
<td>5.9</td>
<td>2.4</td>
<td>1.5</td>
</tr>
<tr>
<td>3–Low</td>
<td>1,004 ± 1.6</td>
<td>0.9</td>
<td>1.8</td>
<td>6.4</td>
<td>16.3</td>
<td>59.3</td>
<td>3.9</td>
<td>4.6</td>
<td>4.4</td>
<td>1.6</td>
<td>0.9</td>
</tr>
</tbody>
</table>

1 Analyses were performed on duplicate samples.
2 Sample number corresponds with Table 1 and high, moderate, and low terms are indicative of salt-soluble protein content.
3 Diameter of screen openings that retained particles.
be recovered in less than 24 h (Dänicke et al., 1997). However, digesta was collected proximal to the ceca and originated from a feedstuff low in soluble nonstarch polysaccharides, compared with diets based on rye as evaluated by Dänicke et al. (1997). The efficacy of the method used in the current study has been demonstrated previously. Rochelle et al. (2012) evaluated rate of passage of corn-soybean meal-based diets and recovered 100% of TiO2 from excreta over a 12-h serial collection period using this method. Ileal N, starch, CF, and energy digestibility were calculated as [(diet nutrient or energy content/diet TiO2 content) – (digesta nutrient or energy content/diet TiO2 content)]/(diet nutrient or energy content/diet TiO2 content) × 100.

**Statistical Analyses**

Data were analyzed as a one-way treatment structure in a randomized complete block design. Cage location was the blocking factor. Each treatment was represented by 7 replicate cages. Analysis of variance was performed using PROC MIXED (SAS Institute, 2009) by the following mixed-effects model:

\[ Y_{ij} = \mu + \rho_i + \tau_j + \varepsilon_{ij}, \]

where \( \mu \) is the overall mean; the \( \rho_i \) are identically and independently normally distributed random block effects with mean 0 and variance \( \sigma^2_\rho \); the \( \tau_j \) are fixed factor level effects corresponding to the jth corn source (experiment 1 or 2, respectively) such that \( \Sigma \tau_j = 0 \); and the random error \( \varepsilon_{ij} \) are identically and independently normally distributed with mean 0 and variance \( \sigma^2 \). Linear relationships between quality variables and energy or nutrient digestibility were evaluated using Pearson’s product-moment correlation via PROC CORR (SAS Institute, 2009; Dowdy et al., 2004). Statistical significance was established at \( P \leq 0.05 \).

**RESULTS AND DISCUSSION**

The cost of providing dietary energy and protein is continually increasing and represents a large percentage of the cost of broiler production (Donahue and Cunningham, 2009; Angel et al., 2011). Variability in corn quality may affect feed conversion by altering utilization of nutrients and energy by broilers. The objective of the current research was to evaluate corn quality in vitro and in vivo and determine relationships between SSP and vitreousness with nutrient and energy digestibility.

**Corn Quality Screening Assay**

The CP and CF content of the 12 corn sources were comparable with values published previously (Kasim and Edwards, 2000; Table 1). Corn sources that had a similar proximate composition and diverse SSP (25.7 to 49.2%) were selected in pairs to create low, moderate, and high quality classifications in order of increasing salt-soluble protein content, respectively. Proximate composition was similar among the selected corn sources with the exception of corn source 2 which had much higher CP (8.7 vs. < 7.5%) compared with the other corns. Corns selected for the determination of nutrient digestibility had 65.6 to 66.8% starch, 3.863 to 3.924 kcal/kg of gross energy, 7.1 to 8.7% CP, 3.0 to 3.3% CF, and 2.3 to 2.5% crude fiber (corrected to an 88% DM basis; Table 2). Mean particle size (Dgw) of the 6 corns averaged 976 μm following milling through a 3-mm screen. The effect on nutrient utilization was likely minimum because the difference between the highest and lowest corn particle sizes was only 84 μm (Table 3).

Salt-soluble protein content provides an indication of susceptibility of the protein matrix and embedded starch granules to enzymatic attack. Although useful in this regard, SSP does not identify cause and effect because values may vary due to several factors, such as content of the various protein fractions, drying at high temperature, moisture content, and maturity at harvest (Wall et al., 1975; Odjo et al., 2012). Chemically, SSP depends on the concentrations of albumins, globulins, glutelins, and zein, as well as sulfhydryl oxidation, denaturation, and protein aggregation caused by the drying process (Wall et al., 1975).

Corns with SSP varying from 25.7 to 49.2% were obtained without major differences in vitreousness (Table 2). Vitreousness values varied by less than 5% among the 6 corn sources (mean 59.2%) indicating that differences in SSP values may not have been related to varied protein composition or the abundance of either endospermic fraction. Instead, variation in SSP may have occurred due to chemical changes such as denaturation, functional group modification, and disulfide interchange induced by postharvest drying (Wall et al., 1975). Blasel et al. (2006) determined that access to starch by amylase and amyloglucosidase was not compromised below 60% vitreousness. Because all corn sources in the current experiment fell below this range, it is not likely that vitreousness had an appreciable effect on nutrient digestibility.

**Ileal Energy and Nutrient Digestibility**

In the current study, ileal digestibility of N, CF, and starch did not differ significantly (\( P > 0.05 \)) among sources of corn (Table 4). Ileal digestible energy (IDE) and AMEn of the high quality corns were 115 and 56 kcal/kg higher, respectively, than the low quality corns (\( P < 0.02 \)). Salt-soluble protein content was positively correlated with IDE (\( r = 0.48; P < 0.001 \); Table 5) and AMEn (\( r = 0.81; P < 0.001 \)) of the corn sources. Moreover, ileal N digestibility was positively correlated with IDE (\( r = 0.38; P = 0.013 \)) which may reflect the relationship between protein solubility and energy utilization. These associations may have occurred because SSP is related to the protein-starch interface and has
been demonstrated to affect starch and protein separation in the wet-milling process (Malumba et al., 2009).

Starch granules and protein bodies within the endosperm enlarge during maturation becoming tightly associated with an amorphous continuous protein matrix (Duvick, 1961; Christianson et al., 1969). The content of zein, the primary glutelin-associated protein in dent corn hybrids (Boundy et al., 1967), may vary due to genetic strain differences or the extent of maturity at harvest (Bressani and Conde, 1961) and is negatively associated with biological value (Mitchell et al., 1952). Interaction with protein reduces access to starch granules (Rooney and Pflugfelder, 1986), and thus, any impairment of protein solubility that limits proteolytic hydrolysis may affect both protein and starch digestion.

Unexpectedly, differences in energy utilization from the 6 corn sources were obtained without detecting a change in ileal N, starch, or fat digestibility (Table 4). Apparent ileal N digestibility varied by 4 percentage points but was not different among the corns \((P = 0.573)\). Rivera et al. (1978) reported no difference in true N digestibility (5 percentage point numerical difference) of corns dried at different temperatures and fed to rats, but linear reductions in availability of several amino acids, including Lys, Met, Ile, Val, and Trp, which vary in their GE content were observed. Corn drying may have affected the interrelationship between fat, N, and energy as reflected in significant correlations between these variables. Apparent IDE was correlated with ileal digestibility of N and fat \((r = 0.38 \text{ and } 0.31; \ P < 0.05, \text{ respectively})\) and ileal fat digestibility was correlated with ileal N digestibility \((r = 0.39; \ P = 0.013)\). Excessive drying temperature affects oil yield from wet-milled corn, irrespective of kernel damage (MacMasters et al., 1959; Weller et al., 1989). The germ contains mostly albumin, globulin, and glutelin proteins (Peri et al., 1983) and drying may have affected oil accessibility due to interactions with non-salt-soluble proteins, because ileal fat digestibility and salt-soluble protein content were not correlated \((P > 0.05)\). The fact that ileal N digestibility and ileal starch digestibility exhibited a negative correlation \((r = -0.41; \ P < 0.001)\) further indicates that proteins other than those of the salt-soluble fraction may have been damaged in some corns and influenced correlations with other nutrients. However, it should be noted that coef-

### Table 4. Ileal nutrient digestibility, digestible energy, and AME\(_n\) of corn selected to vary in salt-soluble protein content and to have similar proximate composition\(^1\,2\).

<table>
<thead>
<tr>
<th>Sample(^3)</th>
<th>Corn intake(^4) (kg/bird)</th>
<th>Nitrogen (%)</th>
<th>Crude fat (%)</th>
<th>Starch (%)</th>
<th>IDE(^5) (kcal/kg)</th>
<th>AME(_n) (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8–High</td>
<td>0.234</td>
<td>77.2</td>
<td>63.1</td>
<td>91.3</td>
<td>3,408</td>
<td>3,342</td>
</tr>
<tr>
<td>2–High</td>
<td>0.228</td>
<td>75.9</td>
<td>69.4</td>
<td>93.6</td>
<td>3,358</td>
<td>3,297</td>
</tr>
<tr>
<td>10–Moderate</td>
<td>0.227</td>
<td>75.1</td>
<td>66.2</td>
<td>91.9</td>
<td>3,316</td>
<td>3,310</td>
</tr>
<tr>
<td>7–Moderate</td>
<td>0.221</td>
<td>75.0</td>
<td>67.5</td>
<td>90.5</td>
<td>3,322</td>
<td>3,314</td>
</tr>
<tr>
<td>1–Low</td>
<td>0.220</td>
<td>74.1</td>
<td>63.6</td>
<td>92.3</td>
<td>3,248</td>
<td>3,262</td>
</tr>
<tr>
<td>3–Low</td>
<td>0.217</td>
<td>74.0</td>
<td>64.1</td>
<td>91.5</td>
<td>3,287</td>
<td>3,265</td>
</tr>
<tr>
<td>SEM</td>
<td>0.006</td>
<td>1.4</td>
<td>2.5</td>
<td>0.8</td>
<td>34</td>
<td>23</td>
</tr>
</tbody>
</table>

\(^1\) Analyses of corn (mixed with 0.5% TiO\(_2\)) were conducted on quadruplicate samples and analyses of digesta and excreta were conducted on duplicate samples on an as-fed basis. Nitrogen and energy digestibility were calculated on an apparent basis.

\(^2\) Values are least squares means of 7 replicate cages of 8 birds per cage at 30 d of age.

\(^3\) Sample number corresponds with Table 1 and high, moderate, and low terms are indicative of salt-soluble protein content.

\(^4\) Determined from 29 to 30 d of age.

\(^5\) Ileal digestible energy.

### Table 5. Pearson’s product-moment correlation (r-values) between in vitro assays and nutrient utilization\(^1\).

<table>
<thead>
<tr>
<th>Item(^2)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt-soluble protein</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitreousness</td>
<td>0.07</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AME(_n)</td>
<td>0.81**</td>
<td>0.04</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDE</td>
<td>0.48**</td>
<td>−0.04</td>
<td>0.36*</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IND</td>
<td>0.23</td>
<td>0.03</td>
<td>0.21</td>
<td>0.38*</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IFD</td>
<td>0.03</td>
<td>0.10</td>
<td>0.04</td>
<td>0.31*</td>
<td>0.39*</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>ISD</td>
<td>0.10</td>
<td>0.13</td>
<td>−0.11</td>
<td>0.25</td>
<td>−0.41**</td>
<td>−0.08</td>
<td>1.00</td>
</tr>
</tbody>
</table>

\(^1\) Corns were primarily selected based on salt-soluble protein content.

\(^2\) IDE = ileal digestible energy; IND = ileal N digestibility; IFD = ileal fat digestibility; ISD = ileal starch digestibility.

\(* P < 0.05; ** P < 0.01.\)
ficients among ileal nutrient digestibility variables were rather low. Additional research should further explore the interrelationships among N, starch, and fat digestibility in dent corn, especially with respect to energy utilization.

Differences in the utilization of energy may have also been influenced by corn intake. Bhuiyan et al. (2010) reported a reduction in feed intake of 21-d-old broilers fed diets formulated with corn dried at 100°C compared with 80 or 90°C. In the current study, it is likely that some differences in SSP were related to drying temperature because SSP is highly negatively correlated with drying temperature (r = −0.99; Malumba et al., 2009) and because feed intake declined with SSP (P < 0.05). Any comparison between these studies cannot be made because we collected independent sources of corn that may or may not have varied widely in artificial drying scheme and Bhuiyan et al. (2010) did not measure SSP. Regardless, Sibbald (1975) demonstrated that AMEn of wheat and corn oil in roosters increased with increasing intake and thus, corn intake may have influenced AMEn in a similar manner in the current study.

Corn provides the majority of AMEn in corn-soybean meal-based diets, and thus, it is intuitive that starch digestibility would be associated with utilization of energy. However, in the current study, starch digestibility was not correlated with AMEn or IDE (P > 0.05). Any association between these variables may not always be observed. For example, AMEn of wheat fed to pigs has varied by nearly 500 kcal/kg, with little to no change in starch digestibility (Wiseman, 2006). Differential fermentation of undigested starch by cecal microflora may potentially remove the relationship between starch digestibility and AMEn by altering energy content more in some samples compared with others. Moreover, variables such as the rate of starch digestion may affect nutrient assimilation as well as the observed relationship between starch and energy utilization.

In broilers, the rate of starch digestion varies among feedstuffs (Weurding et al., 2001). Weurding et al. (2001) determined that the rates of starch digestion were different between hammer-milled and roller-milled corn (2.6 vs 3.1 kd) although the extent of digestion was equal (97%). Studies in pigs also indicate that starch digestion may occur at different rates independent of ileal digestibility, affecting the utilization of dietary nutrients (van der Meulen et al., 1997; Li et al., 2008). Diets containing 65% corn or pea starch were fed to gilts and net portal flux of glucose and amino acids were determined (van der Meulen et al., 1997). Although starch digestibility of corn and pea starch in pigs are reported to be similar (Everts et al., 1996), net portal glucose flux was higher for corn starch compared with pea starch, and net portal flux of most amino acids were higher for pea starch, despite a lower ileal amino acid digestibility (Everts et al., 1996). This effect may occur due to differences in insulin and glycemic responses, as well as the amount of fermentable substrate reaching the hindgut (van der Meulen et al., 1997; Weurding et al., 2001) and subsequent release of enteric hormones such as peptide YY and glucagon-like peptide-1 that affect gastric emptying (Tatemoto et al., 1982; Suzuki et al., 1983; Nauck et al., 1997).

Another possibility is that the level of analysis affected the association between starch and AMEn. In the current study, starch digestibility was measured at the ileal level and AMEn was measured at the fecal level. Microbial fermentation of undigested starch may have increased AMEn of some corn samples more than others, removing the relationship between the 2 variables. Further research should evaluate the effects of corn quality on the cecal flora, enteric hormones, and the relationship between starch digestibility and AMEn to better understand the effects of nutrient variability on energy utilization.

In conclusion, these data indicated that evaluation of different sources of corn by chemical indices rather than the current grading system may be beneficial in reducing nutrient variability between calculated and analyzed values. Because protein solubility is associated with energy utilization, SSP may provide a tool to evaluate nutritional quality. Assessment of corn quality by these methods may serve to identify corn that have unusually high or low AMEn, thus providing a means to formulate broiler diets with increased precision. However, the current data do not provide a means of predicting specific nutrient content or availability. Further research is needed to validate these methods in vivo. Results reported herein indicated that corn sources with similar composition varied in their digestible energy and AMEn content and that SSP may be useful for identifying corn sources that differ in availability of energy.

REFERENCES

AFNOR. 2008. Méthode Promatest d’évaluation de la dénaturation des protéines Thermosensibles. NF-V03-741. AFNOR.


